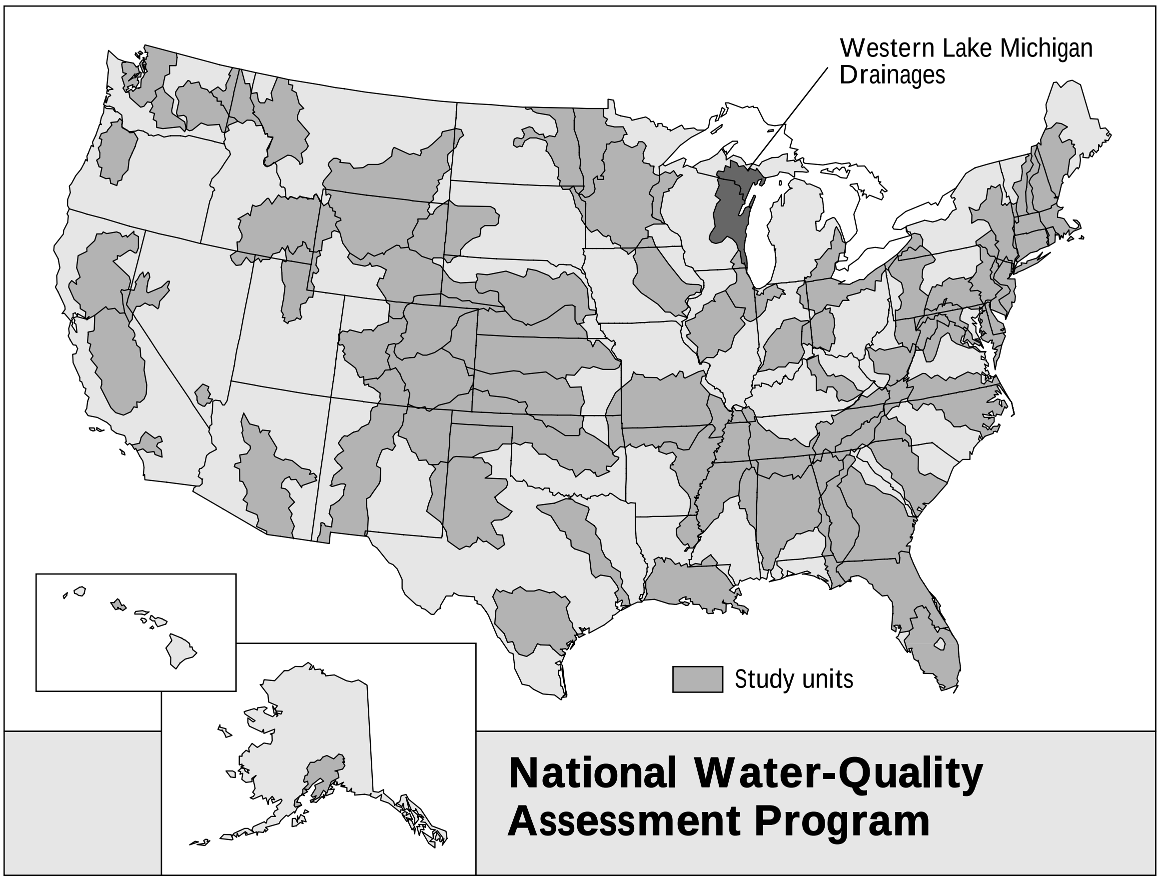
U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 96–4038–E

Benthic Algae of Benchmark Streams in Agricultural Areas of Eastern Wisconsin



Benthic Algae of Benchmark Streams in Agricultural Areas of Eastern Wisconsin

By Barbara C. Scudder and Jana S. Stewart

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 96–4038–E

NATIONAL WATER-QUALITY ASSESSMENT PROGRAM
WESTERN LAKE MICHIGAN DRAINAGES

Middleton, Wisconsin
2001

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CONVERSION FACTORS, VERTICAL DATUM, ABBREVIATED WATER-QUALITY UNITS, AND MISCELLANEOUS ABBREVIATIONS

Multiply	By	To Obtain
square centimeter (cm^2)	0.155	square inch (in^2)
centimeter (cm)	0.06102	inch (in)
feet (ft)	0.3048	meter (m)
square mile (mi^2)	2.59	square kilometer (km^2)
pound (lb)	453,600	milligram (mg)
gallon (gal)	3.785	liter (L)
square kilometer (km^2)	0.03861	square meter (m^2)

Temperature, in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) by use of the following equation:

$$°F = [1.8(°C)] + 32.$$

Vertical Datum: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Abbreviated water-quality units: Chemical concentrations and water temperature are given in metric units. Chemical concentration is given in milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to one milligram per liter. For concentrations less than 7,000 mg/L, the numerical value is the same as for concentrations in parts per million.

MISCELLANEOUS ABBREVIATIONS

CCA	Canonical Correspondence Analysis
DCA	Detrended Correspondence Analysis
GIS	Geographic Information System
GLEAS	Great Lakes Ecological Assessment Section - Michigan Department of Natural Resources
NAWQA	National Water-Quality Assessment Program
QMH	Qualitative Multihabitat sample
Q/Q2	Instantaneous discharge/calculated flow for 2-year flood
RHU	Relatively Homogeneous Unit
RTH	Richest Targeted Habitat sample
STATSGO	State Soil Geographic Data Base
TWINSPAN	Two Way Indicator Species Analysis
USGS	U.S. Geological Survey
WDNR	Wisconsin Department of Natural Resources
WISCLAND	Wisconsin Initiative for Statewide Cooperation on Landscape Analysis and Data
WMIC	Western Lake Michigan Drainages

ACKNOWLEDGMENTS

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Benthic Algae of Benchmark Streams in Agricultural Areas of Eastern Wisconsin

By Barbara C. Scudder *and* Jana S. Stewart

Abstract

Benthic algae were collected from 20 streams in the Western Lake Michigan Drainages by the U.S. Geological Survey in May and June of 1993 as part of the National Water-Quality Assessment program. These streams were selected to represent "benchmark" streams that were minimally affected by human activities, especially agriculture, for comparison to other streams in similar environmental settings. Streams were chosen from four relatively homogeneous units (RHU's) in agricultural areas with differing texture of surficial deposits and bedrock type.

Blue-green algae were the dominant algal cells at all but 5 of the 20 stream sites, and the most abundant species at these sites was *Calothrix parietina*, a nitrogen-fixer typically found in pristine streams. Most of the taxa at all sites were diatoms. The dominant diatom guilds observed were the *Achnanthes* spp., erect forms, and *Navicula* spp.

Except for three streams thought to have low productivity, the Shannon-Wiener diversity index for diatoms was high at all benchmark streams and indicated either minor stress or no stress on the diatom community. With regard to water quality, additional diatom indexes for 17 of 20 benchmark streams indicated no pollution effects and no significant siltation. All benchmark streams had good to excellent biological integrity and either minor or no impairment of aquatic life with regard to diatoms.

A variety of algal metrics and relative abundances of diatom morphological guilds correlated with basin-, segment-and reach-level habitat characteristics, including drainage area, basin drainage density, basin soil permeability, Q/Q2 (instantaneous discharge measured at time of sampling divided by the estimated 2-year flood discharge), stream length, and average width of natural riparian vegetation. Algal taxa richness decreased with higher percentages of agricultural land and lower percentages of forested land. The relative abundance of pollution-tolerant diatoms was higher in streams where the basin land was primarily agricultural as compared to forested. The Shannon-Wiener diversity index for diatoms, the percentage of diatom taxa, and the percent relative abundances of diatom cells, pollution tolerant diatoms, *Achnanthes* spp., erect diatom forms, nitrogen-fixing algae, and blue-green algae differed significantly among either RHU's or ecoregions. Higher abundances of pollution-sensitive diatoms and a higher pollution index indicate that water quality in sampled streams in the North Central Hardwood Forests ecoregion may be less degraded than in streams in the Southeastern Wisconsin Till Plains ecoregion. Algal taxa richness decreased as specific conductance, dissolved nitrate plus nitrite, and suspended sediment increased. This relation may indicate a negative effect of agricultural activities on the algal taxa richness of the stream. Pollution-tolerant diatoms and the pollution index increased as these and additional factors correlated with agriculture increased.

Multivariate analyses indicated multiple scales of environmental factors affect algae. Although two-way indicator species analysis (TWINSPAN), detrended correspondence analysis (DCA), and canonical correspondence analysis (CCA) generally separated sites according to RHU, only DCA ordination indicated a separation of sites according to ecoregion. Environmental variables correlated with DCA axes 1 and 2—and therefore indicated as important explanatory factors for algal distribution and abundance—were factors related to stream size, basin land use/cover, geomorphology, hydrogeology, and riparian disturbance. CCA

analyses with a more limited set of environmental variables indicated that pH, average width of natural riparian vegetation (segment scale), basin land use/cover and Q/Q2 were the most important variables affecting the distribution and relative abundance of benthic algae at the 20 benchmark streams.

INTRODUCTION

The Western Lake Michigan Drainages (WMIC) is one of 20 study units in which investigations were begun in 1991 as part of the National Water-Quality Assessment (NAWQA) Program of the U.S. Geological Survey. The NAWQA Program was designed to (1) provide a nationally consistent description of current water-quality conditions for a large part of the Nation's freshwater streams, rivers, and aquifers, (2) describe trends in water quality over time, and (3) improve understanding of the primary natural and human factors that affect water-quality conditions (Hirsch and others, 1988). Biological data, along with physical and chemical data, are collected in an integrated assessment of water quality, and are important endpoint indicators of the physical and chemical effects—a result of human activity on the landscape—on water resources.

Algal communities respond to a wide variety of environmental gradients, through changes in the relative abundance of different species (Molloy, 1992; Leland, 1995; Reid and others, 1995; Pan and others, 1996; Kutka and Richards, 1996; Cuffney and others, 1997). These environmental gradients may be defined by a range of values for physical and chemical characteristics of streams or watersheds, including, but not limited to, velocity, specific conductance, nutrient concentration, and land use/cover. This response can provide a temporally integrated measure of environmental changes at a site. Algal communities have been used for several decades to assess water quality in rivers, and quantitative methods have been continuously improving (Palmer, 1963; Patrick, 1963; Reid and others, 1995; Whitton and Kelly, 1995; Stevenson and others, 1996; Lewis and Wang, 1997; McCormick and Cairns, 1997; Hill and others, 2000). Certain algae are quite tolerant of different types of pollution and, under certain conditions, may increase in number to the point at which their presence constitutes a nuisance. Other algae are highly intolerant. Many researchers (Descy, 1979; Lange-Berlalot, 1979; Molloy, 1992; Bahls, 1993; Van Dam and others, 1994; Kelly and others, 1995) have investigated the pollution tolerances of algae, primarily diatoms.

Algae and other aquatic communities have been shown to respond to changes commonly associated with agricultural land, such as increases in nutrients and sediment, disturbance in streams, habitat alterations, and reductions in flow. Leland (1995) found that differences in the benthic algal community in streams of the agricultural Yakima River Basin in Washington were related to the amount of dissolved solids, inorganic nitrogen, dissolved phosphorus, and selected habitat variables including turbidity, embeddedness, density of large woody debris, and composition and density of the riparian vegetation. Cuffney and others (1997) related the intensity of agriculture to the types of aquatic communities in the Yakima River Basin. They found that invertebrate and algal communities showed a dramatic decline in condition, based on community measures, at agricultural intensities greater than 50 percent.

Purpose and Scope

This report (1) characterizes benthic algal communities of "healthy" streams that have been minimally affected by agriculture, (2) identifies important environmental factors (habitat and water quality) that influence algal-community structure at sites, and (3) discusses whether these communities differ among areas of relatively homogeneous land use/cover, surficial deposits, and bedrock. The answers to these questions are important for calibration of biotic indexes and for assessing communities that might be observed with restoration of stream sites in these areas. Although considerable attention has been given to problem streams, very little work has been done to define healthy stream communities in the southern agricultural part of the study unit. Results of benchmark-stream studies of invertebrates, fish, and habitat are reported elsewhere (Rheaume and others, 1996b; Sullivan and Peterson, 1997; and Fitzpatrick and others, 1996).

Description of the Western Lake Michigan Drainages

The Western Lake Michigan Drainages study unit (fig. 1, inset map) drains approximately 51, 541 km^2 of eastern Wisconsin and the Upper Peninsula of Michigan and includes several major rivers. The Ford and

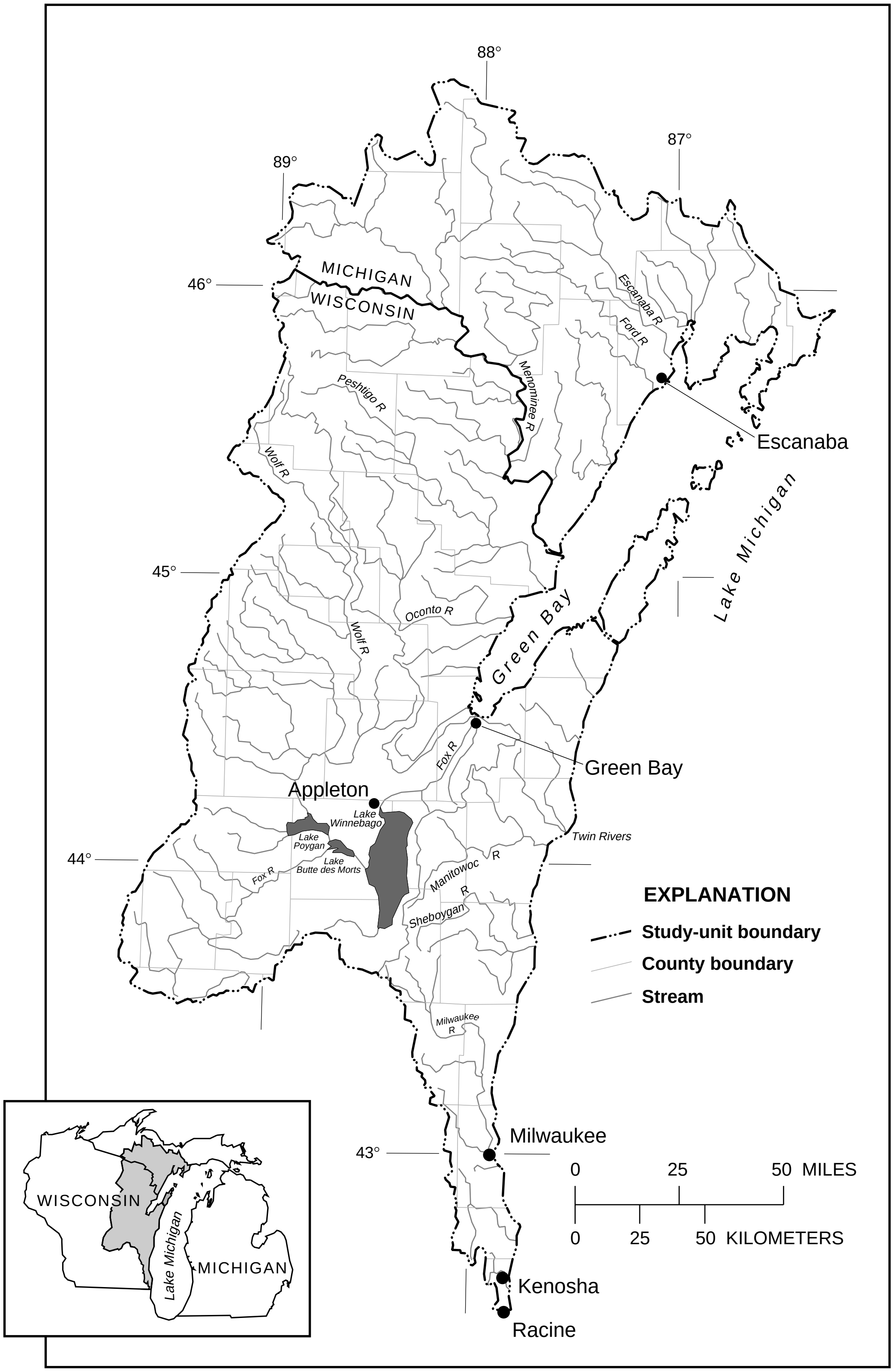


Figure 1. Western Lake Michigan Drainages study unit of the National Water-Quality Assessment Program.

Escanaba Rivers in Michigan, the Menominee River, and the Fox/Wolf River systems drain directly into Green Bay, whereas the Manitowoc, Sheboygan, and Milwaukee Rivers drain directly into the western side of Lake Michigan. The overall population in the study unit is 2,435,000 (U.S. Bureau of the Census, 1991). Major cities and their populations are Milwaukee (628,000), Green Bay (96,000), Racine (84,000), Kenosha (80,000), and Appleton (66,000). Most of these cities lie in the southeastern part of the study unit. Agriculture, primarily dairy operations growing corn, alfalfa, and soybeans, accounts for 37 percent of the total land use in the study unit area. About 40 percent of the study unit, primarily the northwest part, is forested, and much of this land is used for recreational activities and silviculture. Approximately 15 percent of the study unit is wetland.

The ecoregions in the study area, as delineated by Omernik and Gallant (1988), are the Northern Lakes and Forests, North Central Hardwood Forests, Southeastern Wisconsin Till Plains, and Central Corn Belt Plains. Ecoregion boundaries are based on spatial homogeneity of soils, land use, land-surface form, and potential natural vegetation. These areas were delineated by Omernik and Gallant (1988) as a way of summarizing important factors that they believed to be affecting ecosystems.

The study unit was divided into areas referred to as “relatively homogeneous units”, or RHU’s (fig. 2), representing unique combinations of land use/land cover, bedrock geology, and surficial deposits (Robertson and Saad, 1995). These are environmental factors thought to be important in affecting the ambient water quality of the streams. The RHU’s were delineated by overlaying digital thematic maps by use of a geographic information system (GIS).

STUDY DESIGN AND METHODS

Benchmark-Streams Study Design

Twenty sites were selected in four of the largest relatively homogeneous units that are dominated by agricultural land use (fig. 2 and table 1). The four RHU’s differed in their bedrock types and surficial deposits: RHU 1 (carbonate bedrock, clayey deposits, agriculture), RHU 3 (carbonate bedrock, sandy deposits, agriculture), RHU 20 (igneous/metamorphic bedrock, sandy/sand and gravel deposits, forested agriculture), and RHU 26 (sandstone bedrock, sandy/sand and gravel deposits, forested agriculture). RHU’s 1 and 3 are adjacent and lie in the Southeastern Wisconsin Till Plains ecoregion, and RHU’s 20 and 26 are adjacent and lie in the North Central Hardwood Forests ecoregion (fig. 2).

Benchmark sites were selected on the basis of field reconnaissance, discussions with Wisconsin Department of Natural Resources (WDNR) research staff, and judgments as to whether sites met at least one of the following criteria: (1) sampled in 1972 and 1973 by William Hilsenhoff (Hilsenhoff, 1977), and invertebrate biotic index ratings indicated “excellent” or “very good” water quality, (2) fisheries data that indicated excellent to very good water quality, (3) instream habitat restoration for fisheries enhancement, or (4) land management to protect natural riparian vegetation (Rheaume and others, 1996a).

Samples of benthic algae were collected in mid-May to early June 1993 at all 20 benchmark streams, four to six streams per RHU. All sites were wadeable first-to third-order streams with the exception of the Mullet River, which was a fourth-order stream (Strahler, 1957). Most streams were second order.

Data Collection Methods

Algal Community

Sampling for benthic algae followed methods described in Porter and others (1993). Two types of samples were collected: a quantitative sample of the richest targeted habitat (RTH), and a qualitative multihabitat sample (QMH). The RTH sample was collected to assess the relative abundance, composition, and community structure of algal taxa, whereas the QMH sample was collected to determine the occurrence of most of the taxa in the stream reach. All algal samples were identified by The Academy of Natural Sciences of Philadelphia with quality assurance by the Biological Unit of the National Water-Quality Laboratory, U.S. Geological Survey in Lakewood, Colo. Taxonomy is according to that provided by the Biological Unit (John Kingston, U.S. Geological Survey, written commun., 1997; Stephen Porter, U.S. Geological Survey, written commun., 2000). This taxonomic hierarchy is based on Bourrelly (1981, 1985, 1988, 1990) for soft algae, Taylor (1987) for dinoflagellates, and Round and others (1990) for diatoms. The taxonomy also included additional recent revisions for diatoms by Bukhtiyarova and

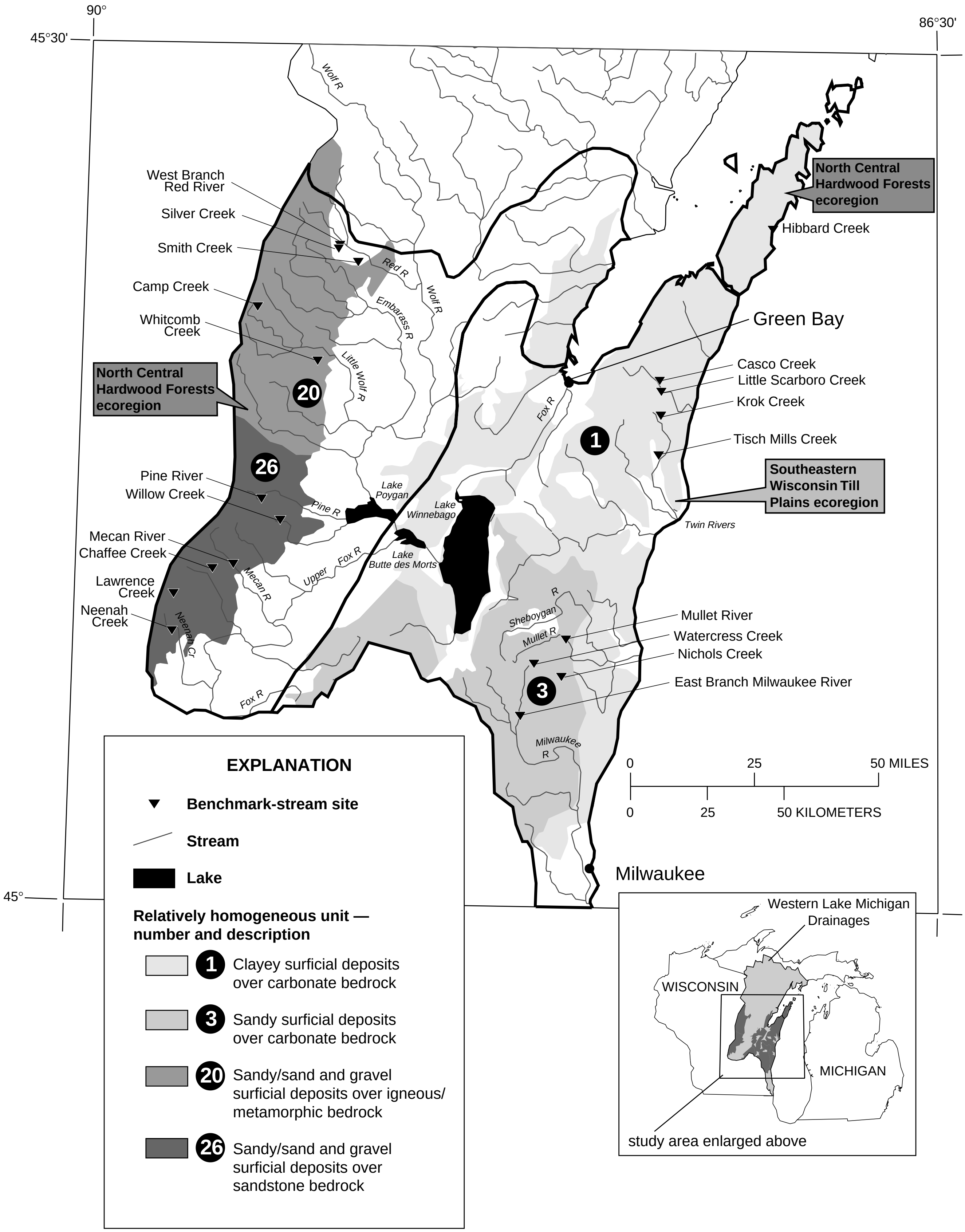


Figure 2. Location of agricultural benchmark-stream sites, ecoregions (Omernik and Gallant, 1988), and four relatively homogeneous units in the Western Lake Michigan Drainages study unit, 1993.

Table 1. Selected information for agricultural benchmark streams and date of benthic algal collections in the Western Lake Michigan Drainages study unit, 1993

[RHU, relatively homogeneous unit]

Site name	Station number	Stream code	Stream order	Latitude	Longitude	Collection date
RHU 1						
Tisch Mills Creek at Tisch Mills, Wis.	040852508	TI	2	44°19'40"	87°38'10"	6/04/93
Krok Creek near Ellisville, Wis.	04085233	KR	2	44°26'34"	87°37'46"	6/05/93
Little Scarboro Creek near Luxemburg, Wis.	040851987	LI	1	44°30'49"	87°37'41"	6/05/93
Casco Creek near Casco, Wis.	04085197	CA	3	44°32'43"	87°38'05"	6/06/93
Hibbard Creek at Jacksonport, Wis.	04085170	HI	2	44°59'16"	87°10'31"	6/06/93
RHU 3						
East Branch Milwaukee River near New Fane, Wis.	04086198	EB	3	43°33'54"	88°11'04"	5/20/93
Nichols Creek near Cascade, Wis.	04086277	NI	1	43°40'50"	88°01'12"	5/21/93
Mullet River near Plymouth, Wis.	04085760	MU	4	43°47'21"	88°00'15"	5/21/93
Watercress Creek near Dundee, Wis.	04086156	WA	2	43°43'03"	88°07'54"	5/22/93
RHU 20						
Whitcomb Creek near Big Falls, Wis.	04079790	WH	2	44°35'10"	89°02'15"	6/1/93
West Branch Red River near Bowler, Wis.	04077605	WB	2	44°55'29"	88°57'21"	6/8/93
Silver Creek near Bowler, Wis.	04077614	SI	2	44°54'48"	88°57'40"	6/8/93
Smith Creek near Bowler, Wis.	04077653	SM	2	44°52'35"	88°52'48"	6/9/93
Camp Creek near Galloway, Wis.	04079589	CM	1	44°44'21"	89°17'17"	6/10/93
RHU 26						
Lawrence Creek near Lawrence, Wis.	04072749	LA	1	43°53'53"	89°36'04"	5/24/93
Neenah Creek near Oxford, Wis.	04072657	NE	2	43°47'25"	89°35'56"	5/25/93
Chaffee Creek near Neshkoro, Wis.	04073248	CH	2	43°58'28"	89°26'34"	5/25/93
Mecan River near Richford, Wis.	04073200	ME	2	43°59'27"	89°21'29"	5/26/93
Willow Creek near Mount Morris, Wis.	04081437	WI	2	44°07'11"	89°10'21"	5/26/93
Pine River at Wild Rose, Wis.	04081407	PI	2	44°10'49"	89°15'04"	5/27/93

Round (1996), Round and Bukhtiyarova (1996), Round and Basson (1997), Krammer (1997a,b), and Lange-Bertalot (1997).

Each RTH sample was a composite of five quantitative samples collected from each of five locations in the stream reach. At most sites, benthic algae were collected from submerged rocks in one upstream and one downstream riffle using a modified syringe sampling device called a NAWQA SG-92 sampler (Porter and others, 1993). Woody snags were sampled at one site in RHU 26 (Chaffee Creek) and at all sites in RHU 20, except the West Branch of the Red River, because no cobble riffles were found. Snags less than or equal to 3 cm in diameter and 10 cm in length were selected; algae were removed from the entire surface with a firm toothbrush and native water, and the surface area of the snag was determined by means of the foil template method (Porter and others, 1993). At two sites, the West Branch of the Red River and Silver Creek (woody-snag sampling also done at this site), a separate sample of gravel was composited from each of five locations in the reach by use of a petite ponar sampler. The gravel was vigorously scrubbed and swirled in a small amount of native water, and the resulting liquid was collected for benthic algae identification and enumeration.

The QMH sample consisted of separate bottles for microalgae and macroalgae. The microalgae QMH sample was an equally weighted composite of all available microhabitat types in the reach (epilithic, epidendric, epiphytic, epipelic, and epipsammic), with equal volumes from each habitat. Algae were collected by scraping, brushing, or suctioning from the microhabitats.

Habitat

Habitat data were collected using methods described in Meador and others (1993) at three spatial scales: basin, stream segment between tributaries, and stream reach. Several of the habitat characteristics measured and reported here represent those thought to be important in determining the distribution and abundance of algal communities. Selected characteristics include basin relief, permeability, erodibility factor, drainage area, basin slope, Q/Q2 (instantaneous discharge measured at time of sampling divided by the estimated 2-year flood discharge), stream length, width of natural riparian vegetation, reach geomorphology, canopy angle, reach embeddedness, reach and riffle velocity, and habitat score. Additional measured characteristics may be found in Fitzpatrick and others (1996).

Water Chemistry

Water-chemistry data were collected and processed by means of standard USGS NAWQA techniques (Shelton, 1994). The samples were analyzed for nutrients at the USGS National Water-Quality Laboratory in Lakewood, Colo. Specific conductance and pH were measured at the time of algal sample collection with a multiparameter water-quality instrument. Chemical constituents and physical properties and characteristics are summarized in Rheaume and others (1996b).

Data-Analysis Methods

Analysis of the benthic algal data was threefold and included (1) basic summary descriptions of the algal taxa at sites and comparison among sites, (2) comparison to established indexes, and (3) comparison of algal-community structure to selected habitat characteristics and environmental variables. Multivariate statistics were used to identify important factors that affect algal-community structure at sites.

Diatom Guilds

Molloy (1992) derived 10 growth-form guilds of diatoms on the basis of patterns of species distributions along longitudinal environmental gradients in three stream-drainage systems in Kentucky. The guild definitions were based on morphological characteristics such as whether cells were (1) small and monoraphid (*Achnanthes* spp.), (2) concave and monoraphid (*Cocconeis* spp.), (3) centric and non-filamentous, (4) filamentous, (5) adnate, (6) erect, (7) biraphid, prostrate, and nonmotile, (8) biraphid, prostrate, and motile (*Navicula* spp.), (9) stalked, and (10) araphid (*Eunotia* spp.). Kutka and Richards (1996) found these guilds to be useful in relating diatom community structure to habitat characteristics for Minnesota. Molloy (1992) growth-form diatom guilds were calculated for taxa using relative abundance from RTH samples.

Algal-Community Measures and Biotic Indexes

Algal-community measures summarize those features that are thought to be important for assessing differences among communities in streams. Dominant phylum and species, relative abundance, indicator taxa, and taxa richness were calculated for all algal taxa and also for diatoms alone. Percent relative abundance of algal groups were calculated for diatoms (division Bacillariophyta), green algae (division Chlorophyta), and euglenoids (division Euglenophyta). For nitrogen fixers, Carr and Whitton (1973), Cuffney and others (1997), Bold and Wynne (1985), and Fairchild and Lowe (1984) were used for reference. An index of biological integrity by Bahls (1993) for diatoms was also calculated using relative abundance data from RTH samples.

The index of biological integrity by Bahls (1993) for diatoms has three metrics: (1) the Shannon-Wiener diversity index (Brewer, 1979), (2) a pollution index, and (3) a siltation index. The value for each index is given a score, and the lowest of all three scores is used to determine the biological integrity rating. The diversity index for diatoms is calculated using log base 2. The pollution index is based on the decimal fraction of diatoms in each of three tolerance groups (most tolerant, less tolerant, and sensitive) of Lange-Bertalot (1979) multiplied by the tolerance-group rating. The pollution index therefore ranges from 1 (all most tolerant) to 3 (all sensitive). The siltation index is the sum of the percent relative abundance of silt-tolerant taxa (*Navicula*, *Nitzschia*, *Surirella*, and *Cylindrotheca*), and values range from 0 to 100. The resulting scores for diversity and siltation were calibrated for the study area using data collected for all streams and dates in the study unit during 1993–95, including fixed monitoring sites (37 stream sites). For calibration of diversity scores, the 25th- and 75th-percentile diversity index values were set as the "lower hinge" and "upper hinge" respectively. Diversity values indicating "no stress" were thus defined as those that equaled or exceeded the 75th percentile (4.31), whereas the diversity values less than the 25th percentile (3.33) indicated "moderate" to "high" stress. Values indicating "minor" stress were defined as those between the 25th and 75th percentile. These percentiles were used as a relatively unbiased method to assign scores in a fashion similar to that used by Hilsenhoff (1987) and Lenat (1993). The break between "moderate" and "high" stress was based on apparent breaks in the frequency plot of values. In a similar fashion, the siltation scores were adjusted slightly from those given by Bahls (1993) for plains streams also on the basis of metrics for all streams and dates sampled in the study unit: the 75th-percentile siltation index value and apparent breaks in the frequency plot of values. In the modified index, siltation scores less than 40 indicated no siltation, between 40 and 60 indicated minor siltation, between 60 and 80 indicated moderate siltation, and greater than 80 indicated heavy siltation.

Stream habitat data were summarized by Fitzpatrick and others (1996). From a subset of these data, the Michigan Department of Natural Resources Great Lakes Environmental Assessment Section (GLEAS) Procedure 51 was used to provide an overall, qualitative measure of habitat suitability for the benchmark streams (Michigan Department of Natural Resources, 1991). Nine metrics are included in the procedure: bottom substrate and available cover, embeddedness, water velocity, flow stability, deposition/sedimentation, pools-riffles-runs-bends, bank stability, bank vegetation, and streamside cover. The sum of each of these scores is compared to scores from GLEAS reference sites. The highest total score possible is 135; four categories are set as follows: excellent (111–135), good (75–102), fair (39–66), and poor (0–30). Land use/cover (Level 1) was calculated from the WISCLAND (Wisconsin Initiative for Statewide Cooperation on Landscape Analysis and Data), satellite-derived statewide land-cover data (Lillesand and others, 1998). The soil erodibility factor quantifies the susceptibility of soil particles to detachment and movement by water (U.S. Department of Agriculture, 1991).

Water Chemistry

Water-chemistry samples were collected on two dates in 1995, during relatively low flows. The resulting values for analyzed constituents are summarized in Rheaume and others (1996b). Spearman rank correlations are based on mean values for the April and June or July 1995 sampling dates, except at the five sites where a single sample was collected, in which case the April 1995 sample was used. Results of correlations using a single date (April 1995) against mean values for the two 1995 sampling dates were similar; however, correlations were stronger when sample means were used. Values for specific conductance, pH, and velocity were measured at the time of algae sample collection during 1993.

Statistical Analyses

The SAS statistical software package (Version 6.12, SAS Institute, 1996) and SYSTAT

(Version 7.0, SPSS, Inc., 1997) statistical package were used for basic statistical tests. The SYSTAT package was used in conjunction with Excel Version 4.0 spreadsheets of the raw data and calculated metrics. Excel Version 4.0 also was used for basic descriptive statistics and for summarizing the data. Nonparametric Spearman rank correlation (Iman and Conover, 1983; Johnson and Wichern, 1992) was used to check for relations between algal-community metrics and environmental variables. The Kruskal-Wallis and Wilcoxon tests (Iman and Conover, 1983) in SAS were used to identify significant differences among algal-community metrics with respect to selected environmental variables such as RHU and ecoregion. The Tukey studentized range test (Neter and others, 1985) in SAS was used to identify which groups from the Kruskal-Wallis test were similar among the environmental variables at the 95-percent confidence level. Unless noted otherwise, significant correlations are those where the probability of a Type I error is less than 5 percent ($p < 0.05$), and these correlations are discussed only where the absolute value of the Spearman rho (ρ) is greater than or equal to 0.45.

Multivariate statistics used to examine the data included two-way indicator species analysis (TWINSPAN) (Hill, 1979a), detrended correspondence analysis (DCA) (Hill, 1979b), and canonical correspondence analysis (CCA) (Ter Braak, 1986). Except for TWINSPAN, these analyses were done by means of the CANOCO 4 computer program (Ter Braak and Smilauer, 1998). For TWINSPAN, relative-abundance data were first transformed to percentage data because the number of algal cells collected varied widely from site to site. The default pseudospecies cut levels were used on percentage data so that groupings would be less affected by large numbers of a single species at any one site. TWINSPAN is a two-way classification of samples and species, whereas DCA is an exploratory tool to look at site similarity on the basis of species abundance and composition, without associated environmental factors. The results of the two analyses were compared. CCA was used to examine relations between gradients of environmental variables with species distribution and abundance. Sites and species were plotted in ordination diagrams with vectors representing gradients in selected environmental variables using an intersample focus for scaling. Relative-abundance data were log-transformed before use in DCA and CCA. To satisfy additional requirements of DCA and CCA, the number of algal species was decreased to 58 by including only those species with 5 to 15 occurrences. On the basis of DCA results, initial CCA results, principal components analysis, and correlations among environmental variables, selected environmental variables were deleted from CCA analyses to avoid inclusion of variables that were highly intercorrelated. For example, the percentage of forested land was not used in CCA due to a high negative correlation (Pearson correlation of –0.94) with the percentage of agriculture that resulted in high variable inflation factors. Nine environmental variables were ultimately selected: pH, total phosphorus, percent agriculture, percent wetland, percent grassland, drainage density, Q/Q2, average width of natural riparian vegetation in segment, and average reach velocity. Data for individual environmental variables were examined by plots and transformed as needed to normalize the data for input into CCA. The data for total phosphorus and average reach velocity were log base 10 transformed. Monte Carlo tests were used to determine whether the CCA axes were significant ($p < 0.05$).

BENTHIC ALGAE OF BENCHMARK STREAMS

Abundance and Distribution of Benthic Algae

Algal abundance ranged from a maximum of 21,687,180 cells/cm^2 at Chaffee Creek to a minimum of 255,448 cells/cm^2 at Little Scarboro Creek. A total of 194 algal taxa were identified in RTH samples and 264 taxa in QMH samples from the benchmark streams (appendix 1). The taxa in the RTH sample did not always overlap those in the QMH sample from the same reach, so that 301 taxa were found for RTH and QMH combined for all sites. The reason for this discrepancy may be due to various factors, including patchy distributions of algae or laboratory subsampling, which would have affected uncommon and rare taxa the most. The largest number of algal taxa identified, overall, were from samples collected at the East Branch of the Milwaukee River, with 114 taxa for RTH and QMH combined. The fewest combined taxa were found at the Pine River. Taxa richness for RTH samples alone ranged from 71 at Silver Creek to 32 at Krok Creek. The algal group with the most taxa at all the benchmark sites was the diatoms, and more than 90 percent of the taxa at all sites were in this group; however, diatoms were rarely the most abundant, in terms of number of algal cells at any site.

With respect to algal divisions, blue-green algae cells were dominant at 15 of 20 sites (fig. 3). At Lawrence, Chaffee, Casco, and Smith Creeks, and at the West Branch of the Red River, diatoms as a group were the dominant cells. The only red algae found in the benchmark streams was a filamentous red alga, *Audouinella hermanii*. This alga, which was found at 11 of the 20 sites, accounted for less than 1 percent of the total algal cells, at sites where it was found, except Whitcomb Creek (5.4 percent) and Chaffee Creek (1.6 percent). The occurrence of this alga is generally associated with relatively cool water streams characterized by low nutrient concentration, and little to no organic enrichment or siltation (Sheath and Hambrook, 1990; Junior and others, 1993); *A. hermanii* also is noted for its tolerance to low phosphorus concentrations. Green algae were present but at low abundance at all streams except at the West Branch of the Red River, from which they were absent (table 2). Euglenoids were found in RTH samples only at Lawrence Creek but were collected in QMH samples from 11 sites.

The three dominant species of algae found at each benchmark stream are listed in table 3. The blue-green *Calothrix parietina* was the most abundant algal species at 13 of 20 sites, but it was not found at Little Scarboro Creek and Mecan River nor at four of the RHU 20 streams—Whitcomb Creek, Smith Creek, Camp Creek, and the West Branch of the Red River (table 3). This alga is a nitrogen fixer (Bold and Wynne, 1985) that typically is found in pristine streams that are nitrogen limited, but it also may indicate low nitrogen-to-phosphorus ratios in the water column. Dominance of this alga indicates good to excellent water quality at these sites, and this species was the only nitrogen-fixing alga found at the benchmark streams. Another blue-green alga, *Hydrocoleum brebissonii,* was dominant at the Mecan River; *Lyngbya* spp. were dominant at Tisch Mills, Little Scarboro, and Camp Creeks. *Oscillatoria* sp. 1 was dominant at Whitcomb and Smith Creeks, and this genus of blue-green algae is generally thought to be one of the most tolerant taxa with regard to high organic pollution (Palmer, 1969). *Lyngbya* also is thought to be relatively tolerant. Neither are known to fix nitrogen. At the West Branch of the Red River, the diatom *Achnanthidium clevei* was the dominant algal species (22 percent). A*chnanthidium minutissimum,* a pollution sensitive diatom (Lange-Bertalot, 1979), commonly was subdominant at benchmark sites.

Results for Molloy diatom guilds for the benchmark streams are shown in table 4. In the Kutka and Richards (1996) study of an agricultural basin in Minnesota, the dominant morphological groups of diatoms (guilds) observed were the *Achnanthes* spp., *Navicula* spp., and stalked forms; in our study, however, the dominant guilds observed were the *Achnanthes* spp., followed by erect forms and *Navicula* spp. Stalked forms were an important group and were dominant or subdominant at half of the benchmark sites. *Achnanthes* spp. were dominant at all streams in RHU 20 and dominant or subdominant in RHU 26 streams. Erect forms were dominant over *Achnanthes* spp. at four of six streams in RHU 26. Dominance in RHU 1 was variable among several forms, and *Navicula* spp., erect, and stalked forms were dominant at RHU 3 sites. Relative abundances of *Cocconeis* spp. were small at most sites, and abundances of centric, filamentous, and *Eunotia* spp. (araphid) forms ranged from zero to less than 2.4 percent at all sites. Molloy (1992) found that *Cocconeis* spp., centric, and filamentous forms were more common in downstream large river assemblages, and this finding might explain why they were uncommon in the benchmark streams. Molloy (1992) also found that *Achnanthes*, adnate, erect, stalked, and *Eunotia* taxa were common in stream orders 1 through 5. The erect taxa and *Achnanthes* spp., are small, monoraphid, and generally prostrate with respect to the substrate. The erect taxa are those that are perpendicular to the substrate, araphid or pseudoraphid, not stalked, and often in rosettes. The higher velocities found in headwater streams generally may be associated with diatom communities adapted to disturbance, such as the prostrate-to-surface and stalked forms. As velocity decreases in larger downstream reaches, loosely-attached centric and filamentous forms are found more typically. The guild pattern in the benchmark streams is thus generally in agreement with that found by Molloy (1992) and predictions based on a longitudinal stream gradient by Hambrook and others (1997).

Community Measures and Biotic Indexes of Benthic Algae

Shannon-Wiener diversity of diatoms generally was high at the benchmark streams, except at three streams thought to have low productivity (table 5). Diversity at Little Scarboro Creek, Hibbard Creek, and Pine River ranged from only 2.52 to 2.91, and this is likely associated with low levels of nutrients and productivity at these sites. Shannon-Wiener diversity

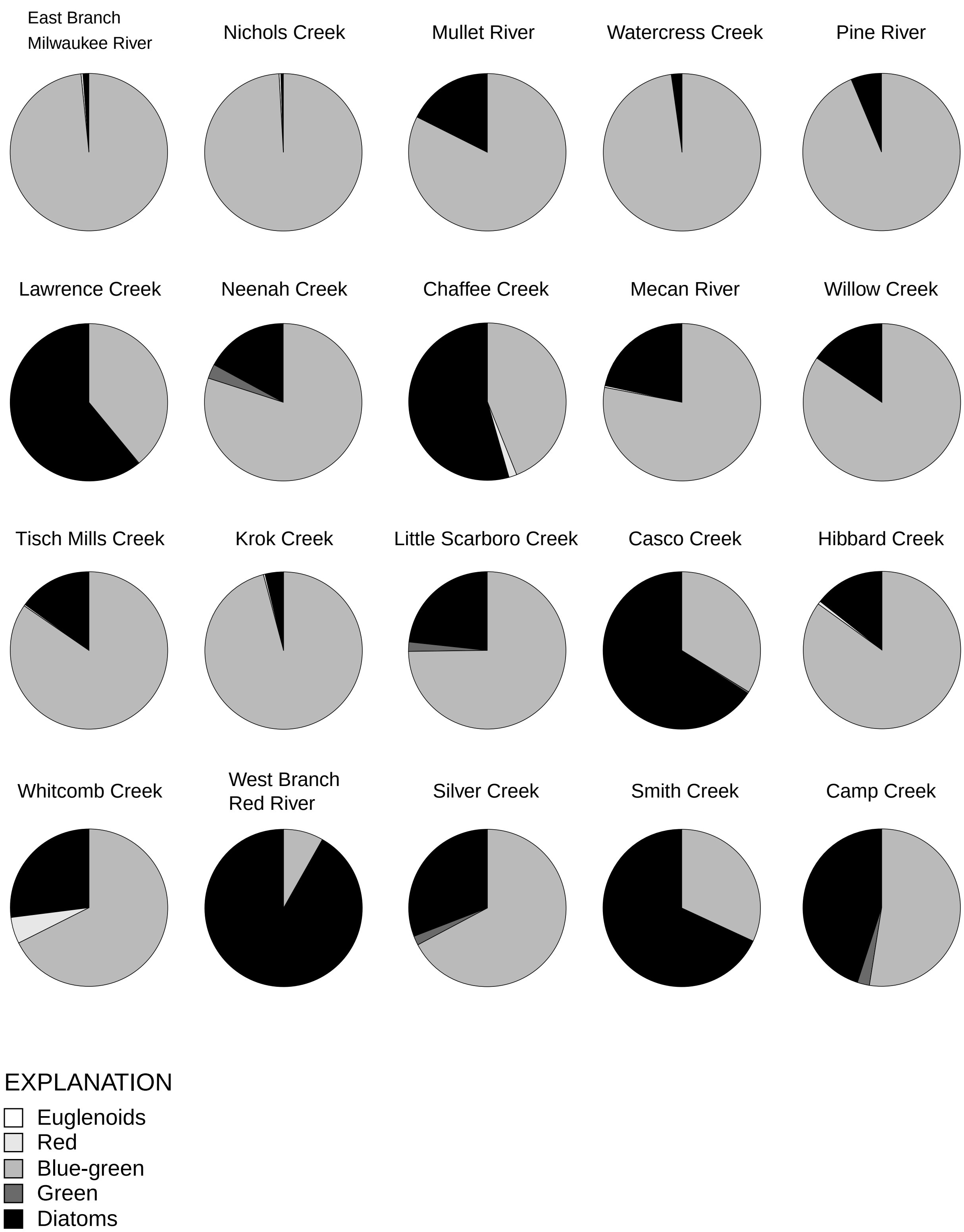


Figure 3. Distribution of benthic algae (percent relative abundance) by algal divisions for 20 agricultural benchmark streams in the Western Lake Michigan Drainages study unit, 1993. (Algal metrics are for the richest-targeted habitat; algal cells by division as percent of total algal cells.)

Table 2. Benthic-algal abundance, taxa richness, and numerical dominance of taxonomic and functional groups from 20 agricultural benchmark streams in the Western Lake Michigan Drainages study unit, 1993

[Algal metrics are for richest-targeted habitat samples except for taxa richness (RTH/QMH) which is for the combined richest-targeted (RTH) and qualitative multi-habitat (QMH) samples; cells/cm^2, algal cells per square centimeter; %, algal cells or taxa by division as percent of total algal cells or taxa; RHU, relatively homogeneous unit]

Stream code[1]	Station number	Total abundance (cells/cm^2)	Taxa richness (RTH)	Taxa richness (RTH/QMH)	Nitrogen-fixing algae (% cells/cm^2)	Blue-green algae (% cells/cm^2)	Green algae (% cells/cm^2)	Euglenoid algae (% cells/cm^2)	Diatoms (% cells/cm^2)	Diatoms (% taxa/cm^2)
					RHU 1					
TI	040852508	6,060,000	49	75	0	84.6	0	0	15.1	91.8
KR	04085233	12,900,000	32	78	95.9	95.9	0	0	3.78	93.8
LI	040851987	255,000	36	68	0	74.8	1.9	0	23.3	91.7
CA	04085197	2,280,000	49	71	33.8	33.8	.34	0	65.8	95.9
HI	04085170	12,300,000	41	85	84.6	85.0	0	0	14.4	92.7
					RHU 3					
EB	04086198	15,100,000	68	114	98.4	98.4	0	0	1.23	97.1
NI	04086277	2,490,000	42	78	99.1	99.1	0	0	0.5	95.2
MU	04085760	14,100,000	44	72	78.9	82.4	0	0	17.6	95.5
WA	04086156	373,000	48	79	84.9	97.8	0	0	2.2	93.8
					RHU 20					
WH	04079790	1,580,000	50	92	0	67.6	0	0	27.0	96.0
WB	04077605	2,130,000	55	73	0	8.18	0	0	91.8	98.2
SI	04077614	3,500,000	71	88	66.4	67.3	1.9	0	30.9	95.8
SM	04077653	476,000	60	103	0	31.9	0	0	68.1	96.7
CM	04079589	897,000	48	79	0	52.5	2.5	0	45.0	93.8
					RHU 26					
LA	04072749	8,580,000	60	89	25.9	39.0	0	.16	60.8	91.7
NE	04072657	16,600,000	52	94	78.8	80.0	3.0	0	17.1	92.3
CH	04073248	21,700,000	63	90	32.2	43.9	0	0	54.4	95.2
ME	04073200	3,920,000	40	64	0	78.0	0	0	21.6	92.5
WI	04081437	11,500,000	52	77	77.9	84.5	0	0	15.5	94.2
PI	04081407	12,900,000	39	64	91.4	93.7	0	0	6.28	92.3

[1]For full stream names refer to table 1.

Table 3. Relative abundance of top three dominant algal species for 20 agricultural benchmark streams in the Western Lake Michigan Drainages study unit, 1993

[Data are for richest targeted habitat samples; RHU, relatively homogeneous unit; %, algal cells as percent of total algal cells per square centimeter]

Site name	Dominant taxon[1] (abbreviated name and %)		
	RHU 1		
Tisch Mills Creek at Tisch Mills, Wis.	LyngSp.1 (82)	AchmMinu (5)	NaviTrip (2)
Krok Creek near Ellisville, Wis.	CalxPari (96)	GompAngu (1)	RhoiAbbr (<1)
Little Scarboro Creek near Luxemburg, Wis.	LyngMart (71)	NaviTrip (9)	GyroNodi (8)
Casco Creek near Casco, Wis.	CalxPari (34)	AmpoPerp (15)	NaviCari (8)
Hibbard Creek at Jacksonport, Wis.	CalxPari (85)	AchmMinu (8)	StauPinn (1)
	RHU 3		
East Branch Milwaukee River near New Fane, Wis.	CalxPari (98)	AudoHerm (<1)	StauPinn (<1)
Nichols Creek near Cascade, Wis.	CalxPari (99)	AudoHerm (<1)	NitzKuet (<1)
Mullet River near Plymouth, Wis.	CalxPari (79)	DiatVulg (5)	HydrBreb (3)
Watercress Creek near Dundee, Wis.	CalxPari (85)	ChamRegu (6)	Cyanoph2 (6)
	RHU 20		
Whitcomb Creek near Big Falls, Wis.	OsciSp.1 (68)	AchmMinu (10)	AudoHerm (5)
West Branch Red River near Bowler, Wis.	AchmClev (22)	GompOliv (8)	OsciSp.1 (8)
Silver Creek near Bowler, Wis.	CalxPari (66)	AchmMinu (4)	NaviTrip (2)
Smith Creek near Bowler, Wis.	OsciSp.1 (30)	AchmMinu (28)	AchmPusi (5)
Camp Creek near Galloway, Wis.	LyngSp.1 (51)	AchmMinu (14)	AmpoPerp (3)
	RHU 26		
Lawrence Creek near Lawrence, Wis.	CalxPari (26)	AchmMinu (14)	AmpoPerp (6)
Neenah Creek near Oxford, Wis.	CalxPari (79)	NaviCari (3)	Chlorop2 (3)
Chaffee Creek near Neshkoro, Wis.	CalxPari (32)	MartMart (13)	HydrBreb (12)
Mecan River near Richford, Wis.	HydrBreb (57)	LyngSp.1 (21)	MartMart (4)
Willow Creek near Mount Morris, Wis.	CalxPari (78)	HydrBreb (6)	MartMart (5)
Pine River at Wild Rose, Wis.	CalxPari (91)	AchmMinu (3)	HydrBreb (2)

[1]Full scientific name of dominant taxon listed in appendix 1.

Table 4. Relative abundance of Molloy diatom guilds at 20 agricultural benchmark streams in the Western Lake Michigan Drainages study unit,1993

[Data are for richest-targeted habitat samples; %, diatom cells per square centimeter (cm^2) in specified Molloy guild as percent of all diatoms in cells per cm^2; RHU, relatively homogeneous unit]

Stream code[1]	Station number	Molly diatom guild (%)									
		Achnanthes spp.[2]	*Cocconeis* spp.	Centric forms	Filamentous forms	Adnate forms	Erect forms	Biraphid/ prostrate/ non-motile forms	*Navicula* spp.	Stalked forms	Eunotia spp.
RHU 1											
TI	040852508	34.8	1.00	1.0	0.33	12.0	12.7	1.50	21.0	15.7	0
KR	04085233	7.00	0.833	0.33	0	24.2	13.2	0.333	0.50	53.7	0
LI	040851987	1.00	1.50	0	0	7.33	8.83	35.7	43.8	1.83	0
CA	04085197	8.03	9.87	.33	2.3	28.9	8.19	3.01	24.9	14.4	0
HI	04085170	63.0	.333	.17	0	5.67	15.5	.333	1.83	13.2	0
RHU 3											
EB	04086198	7.67	5.17	.17	1.2	8.83	43.0	2.83	13.0	18.2	0
NI	04086277	13.0	8.51	1.0	1.5	2.00	8.50	18.5	29.0	18.0	0
MU	04085760	9.00	.667	1.2	.67	6.67	32.3	.833	40.3	8.33	0
WA	04086156	11.0	2.00	1.0	2.0	5.00	20.0	20.0	14.0	25.0	0
RHU 20											
WH	04079790	45.8	1.83	0	0	4.67	17.3	4.33	14.2	11.8	0
WB	04077605	40.5	10.6	0	0	8.98	11.1	1.58	13.9	13.0	.35
SI	04077614	29.6	6.91	.16	.32	6.43	20.7	8.04	23.3	4.18	.32
SM	04077653	55.0	2.33	0	.33	0.333	11.8	8.67	13.5	6.83	1.2
CM	04079589	40.8	2.50	0	.33	7.17	11.2	10.3	16.3	10.8	.50
RHU 26											
LA	04072749	27.0	3.83	0	0.83	13.2	23.5	25.2	3.83	2.67	0
NE	04072657	19.9	4.15	0	0	3.32	32.7	1.82	22.6	15.6	0
CH	04073248	21.2	4.11	0	.16	5.25	37.9	7.22	17.6	6.57	0
ME	04073200	33.2	9.47	0	.17	5.81	38.2	.830	9.47	2.82	0
WI	04081437	13.7	6.33	.50	0	4.33	57.5	2.33	6.17	9.17	0
PI	04081407	51.8	.667	.33	0	2.33	32.3	1.17	3.50	7.83	0

[1]Refer to table 1 for full stream names and locations.

[2]Diatom guilds from Molloy (1992) based on morphological characteristics.

Table 5. Biotic indexes of benthic diatoms at 20 agricultural benchmark streams in the Western Lake Michigan Drainages study unit, 1993

[Data are for richest-targeted habitat samples; cells/cm^2, diatom cells per square centimeter; %, percent sensitive or tolerant diatom cells per square centimeter (cm^2) as percent of total diatom cells per cm^2; RHU, relatively homogeneous unit]

Site name	Station number	Shannon-Wiener diversity[1]	Bahls' siltation index[2]	Bahls' pollution index[2]	Pollution sensitive diatoms[3] (%)	Pollution tolerant diatoms[3] (%)
RHU 1						
Tisch Mills Creek at Tisch Mills, Wis.	040852508	3.69	22.3	2.71	76.7	6.00
Krok Creek near Ellisville, Wis.	04085233	3.30	.666	2.54	56.8	2.67
Little Scarboro Creek near Luxemburg, Wis.	040851987	2.52	44.3	2.59	60.0	1.00
Casco Creek near Casco, Wis.	04085197	4.12	27.6	2.59	66.6	7.19
Hibbard Creek at Jacksonport, Wis.	04085170	2.85	1.83	2.83	89.3	6.83
RHU 3						
East Branch Milwaukee River near New Fane, Wis.	04086198	4.83	16.3	2.72	77.3	5.33
Nichols Creek near Cascade, Wis.	04086277	4.74	47.5	2.30	42.5	12.0
Mullet River near Plymouth, Wis.	04085760	3.73	41.5	2.60	61.8	1.67
Watercress Creek near Dundee, Wis.	04086156	5.22	33.0	2.36	45.0	9.00
RHU 20						
Whitcomb Creek near Big Falls, Wis.	04079790	3.71	15.8	2.70	76.7	6.67
West Branch Red River near Bowler, Wis.	04077605	4.50	15.0	2.70	76.4	5.99
Silver Creek near Bowler, Wis.	04077614	4.96	25.6	2.71	73.6	2.73
Smith Creek near Bowler, Wis.	04077653	3.96	15.0	2.67	74.7	8.00
Camp Creek near Galloway, Wis.	04079589	4.20	20.2	2.64	74.5	10.2
RHU 26						
Lawrence Creek near Lawrence, Wis.	04072749	4.31	28.5	2.61	62.3	1.33
Neenah Creek near Oxford, Wis.	04072657	4.01	24.5	2.70	70.8	1.16
Chaffee Creek near Neshkoro, Wis.	04073248	4.31	20.9	2.76	76.8	.657
Mecan River near Richford, Wis.	04073200	4.09	9.63	2.82	82.4	.664
Willow Creek near Mount Morris, Wis.	04081437	3.90	6.50	2.86	88.7	2.50
Pine River at Wild Rose, Wis.	04081407	2.91	4.17	2.75	83.2	5.33

[1]From Brewer (1979). Shannon-Wiener diversity index scores were calibrated to the study area and indicate no stress (> 4.30), minor stress (3.30–4.29), and moderate to high stress (2.30–3.29); values are log base 2.

[2]From Bahls (1993). Bahls' siltation index scores were calibrated to the study area and indicate heavy siltation (>80), moderate siltation (60–80), minor siltation (40–60), and no siltation (<40). Bahls' pollution index scores indicate severe pollution (<1.5), moderate pollution (1.50–2.00), minor pollution (2.01–2.50), and no pollution (>2.50).

[3]From Lange-Bertalot (1979).

values for the rest of the benchmark streams ranged from 3.30 to 5.22, and indicated minor or no stress on the diatom community. Half of the diversity index values were above 4.0. According to Brewer (1979), a diversity value of 3 (log 2) is usually related to no pollution or very slight pollution, a value of 2–3 indicates slight pollution, and a value less than 1 indicates heavy pollution. Various researchers have calibrated these indexes slightly, with data from different regions. On the basis of diatom samples from Montana streams, Bahls (1993) used values greater than 3.50 to indicate "no stress," and 2.51–3.50 for minor stress in plains streams. Because he found greater diversity in plains streams compared to that in mountain streams, Bahls used a different scale for mountain streams. Metzmeier's diatom bioassessment index (Kentucky Division of Water, 1994) assigned slightly different rankings for diatom diversity based on results from Kentucky streams.

The National Academy of Sciences (1966) defined pollution as "an undesirable change in the physical, chemical or biological characteristics of our air, land and water that may or will harmfully affect human life or that of desirable species, our industrial processes, living conditions, and cultural assets; or that may or will waste or deteriorate our raw material resources." The type and severity of pollution could either increase or decrease diversity depending on the effect(s) on species richness and evenness of species abundance, the two components of diversity (Patrick, 1973; Stevenson and Pan, 1999). Lange-Bertalot (1979) used the gradual tolerance towards pollution based on benthic diatom occurrence and abundance in the Main and Rhine Rivers of Germany, which are affected by several types of pollution: sewage, as well as waste from chemical and cellulose industries.

Kutka and Richards (1996) stated that the diatom siltation index of Bahls (1993) had potential for assessment of physical habitat in agricultural streams in the Midwest. Results of our study also found the siltation index to provide a useful measure of habitat for agricultural streams in Wisconsin, if the index was calibrated for the sampling region as recommended by Bahls (1993). The siltation index for benchmark streams (table 5) ranged from lows of 1 and 2 at Krok Creek and Hibbard Creek, respectively, to a high of 47 at Nichols Creek. *Navicula* and *Nitzschia* were the primary genera contributing to the siltation index. Diatoms of the genus *Surirella* were absent at all but five sites and were low in number where found. Nevertheless, siltation index values in the 40's at Nichols, Mullet, and Little Scarboro are low, only minor siltation, when calibrated with other non-benchmark sites sampled in the Western Lake Michigan Drainage and indicate only minor siltation. Of 20 benchmark sites, 17 (85 percent) had a siltation index below 40, indicating no significant siltation. The median siltation index was 20.5. A weak ($\rho = 0.42$) positive relation was found between the diatom siltation index and the percentage of silt in surficial deposits of the basin; however, this metric did not correlate to any reach level environmental variables indicative of siltation, such as embeddedness, percent fines, or suspended sediment. The percentage of pollution-tolerant diatoms was positively related ($\rho = 0.78$, $p < 0.001$) to the percentage of fine (<0.062 mm) sediment. Kutka and Richards (1996) found that the siltation index was sensitive to sediment-related variables such as bank erosion.

Bahls' pollution index for 17 of 20 benchmark streams indicated no pollution effects (table 5). Three streams—Nichols, Watercress, and Krok Creeks—had pollution-index values that indicate minor pollution. The percentages of pollution-sensitive diatoms were smallest in these three creeks, ranging from 45.7 to 51.6. The percentage of pollution-sensitive diatoms at the other 17 benchmark sites averaged 74.8 $\pm$ 8.6 (standard deviation). Nichols and Watercress Creeks also had the largest percentages of pollution-tolerant diatoms. *Nitzschia palea*, a very tolerant diatom, was found only in Nichols and Watercress Creeks. Still, sensitive diatoms were found at these streams and, at times, in relatively large abundance. The sensitive diatom *Diatoma vulgare* (Lange-Bertalot, 1979; L. Metzmeier, Kentucky Division of Water, written commun., 1998) was found at seven streams including Watercress Creek, although the relative abundance at this site was small. *Achnanthidium cleveii*, considered to be very sensitive, was found at 15 of 20 sites, but not in Nichols and Watercress Creeks. *Achnanthidium clevei* was originally listed by Lange-Bertalot (1979) as one of the more sensitive species in the group of diatoms considered to be relatively sensitive to pollution. *Achnanthidium clevei* and *A. clevei* var. *rostrata* were both listed by Bahls (1993) as sensitive (group 3). Kentucky Division of Water (L. Metzmeier, written commun., 1998) also placed this species in the sensitive group based on literature review and their database. *Nitzschia dissipata* and *Nitzschia romana* are sensitive species (Lange-Bertalot, 1979; Kelly and Whitton, 1995; Bahls, 1993) that were most abundant or present only at Lawrence and Chaffee

Creeks. If pollution tolerances of other nondiatom algae also are considered, such as *Euglena* spp., *Oscillatoria* spp., *Scenedesmus quadricauda*, and *Audouinella hermannii*, the percentages of pollution-sensitive algae are much smaller for Whitcomb and Smith Creeks, owing to the abundance of mat-forming *Oscillatoria* spp. at the sites (Palmer, 1969; Sheath and Hambrook, 1990).

Biological integrity at all benchmark streams was good to excellent (table 6), with minor to no aquatic-life impairment with regard to diatoms (table 5). Of the 20 streams, 5 received excellent biological integrity scores, and these streams were in RHU's 3, 20, and 26. Diversity scores of 3 (minor stress) were the primary reason for streams rating good as opposed to excellent; as stated earlier, most streams received ratings indicating no pollution and no siltation. Perhaps the calibration procedure used for diversity scores, which included additional streams ranging in integrity from excellent to poor and diversity ratings from moderate to no stress, was not an effective method for setting the cutoff points for scores derived from diversity values. In only one case (Nichols Creek), however, was habitat rated excellent and the biological integrity rated one category lower, as good. Biological-integrity ratings were similar in 13 of 20 cases to the ratings given for habitat using GLEAS evaluations. Silver Creek was the only stream that received an excellent rating in both biological integrity and habitat.

Relations Between Benthic Algal Communities and Environmental Variables

Habitat

We observed correlations between most Molloy diatom guilds and some habitat characteristics (table 7). Kutka and Richards (1996) also found that the abundance of several of Molloy's guilds were significantly ($\rho \geq 0.5$) related to reach-level habitat characteristics, including flood width and depth, percent canopy, percent shallow, fines, and substratum score. In the benchmark stream study, the relative abundance of *Achnanthes* spp. was positively correlated with the average width of natural riparian vegetation in the segment ($\rho = 0.61$, $p < 0.01$) (Fitzpatrick and others, 2000) and the percentage of run in the reach ($\rho = 0.47$) but negatively correlated with the percentage of riffle ($\rho = -0.52$). The reason for this negative correlation with riffles is unclear. The strongest ($p < 0.001$) guild

Table 6. Index of biologic integrity scores for benthic diatom communities and habitat evaluation results for 20 benchmark streams in the Western Lake Michigan Drainages study unit, 1993

[Index of biological integrity determined according to Bahls (1993) and calibrated for the Western Lake Michigan Drainages. Habitat evaluation results were determined by Fitzpatrick and others (1996) according to the methods of the Great Lakes Environmental Assessment Section (GLEAS) of the Michigan Department of Natural Resources, 1991. Symbols are ●, excellent; ◓, good; ⊖, fair; ⊙, poor; ○, very poor.]

Stream name	Index of biological integrity	Habitat evaluation
RHU 1		
Tisch Mills Creek	◓	◓
Krok Creek	◓	◓
Little Scarboro Creek	◓	◓
Casco Creek	◓	◓
Hibbard Creek	◓	◓
RHU 3		
East Branch Milwaukee River	●	◓
Nichols Creek	◓	●
Mullet River	◓	◓
Watercress Creek	◓	⊖
RHU 20		
Whitcomb Creek	◓	⊖
West Branch Red River	●	◓
Silver Creek	●	●
Smith Creek	◓	◓
Camp Creek	◓	◓
RHU 26		
Lawrence Creek	●	◓
Neenah Creek	◓	◓
Chaffee Creek	●	◓
Mecan River	◓	◓
Willow Creek	◓	◓
Pine River	◓	◓

Table 7. Spearman-rank correlations (rho) between percent relative abundance of Molloy diatom guilds and habitat characteristics for 20 agricultural benchmark streams in the Western Lake Michigan Drainages study unit, 1993

[Diatom guilds are based on data for richest-targeted habitat samples and morphological guilds from Molloy (1992). Correlations are shown with Spearman rho ≥ 0.5 and $p < 0.05$; *$p < 0.01$, **$p < 0.001$, --, no significant correlation; n = 20 sites, except that correlations with percent riffle and run are for 19 sites; no data were available for these characteristics at Smith Creek; average width of natural riparian vegetation is for segment. % Molloy diatom guild, diatom cells per square centimeter (cm^2) in specified Molloy guild as percent of total diatom cells per cm^2; %, percent; m, meters; in/hr, inches per hour; km^2, square kilometers; m/km, meters per kilometer; km, kilometers; ft/s, feet per second]

Habitat characteristic	% Molloy diatom guild							
	***Achnanthes* spp.**	***Cocconeis* spp.**	**Centric forms**	**Adnate forms**	**Erect forms**	**Biraphid/ prostrate/ nonmotile forms**	***Navicula* spp.**	**Stalked forms**
Basin relief (m)	--	--	--	--	0.51	--	--	--
Permeability (in/hr)	--	--	--	--	.72**	--	--	--
Erodibility factor	--	--	0.66*	--	--	--	--	0.47
Drainage area (km^2)	--	--	--	--	.54	-0.71**	--	--
Basin slope (m/km)	--	--	--	-0.48	--	.57*	--	--
Q/Q2 (%)	--	--	-.64*	--	--	--	--	--
Stream length (km)	--	--	--	--	--	-.54	--	--
Cumulative stream length (km)	--	--	--	--	--	-.55	--	--
Average width of natural riparian vegetation (m)	0.61*	--	--	--	--	--	--	--
Riffle in reach (%)	-.52	--	.54	--	--	--	--	--
Run in reach (%)	.47	--	--	--	--	--	--	--
Mean canopy angle (degrees)	--	--	--	--	.48	--	--	--
Mean width/depth ratio	--	--	.58*	--	--	-.70**	--	--
Average velocity of reach (ft/s)	--	--	--	--	.46	--	--	-.56
Average velocity of riffles (ft/s)	--	0.51	--	--	--	--	--	--
Average embeddedness of riffles (%)	--	--	.58*	--	--	--	--	--
Average embeddedness of reach (%)	--	--	.54	--	--	--	--	--
GLEAS score	--	--	--	--	--	--	0.50	--

correlations we found were for increased relative abundance of erect forms with increasing soil permeability in the basin ($\rho = 0.72$), and decreased relative abundance of biraphid forms with increasing drainage area ($\rho = -0.71$) and mean width/depth ratio of the stream ($\rho = -0.70$). Increased basin relief, drainage area, mean canopy angle, and average velocity of the reach were related to increasing relative abundance of erect forms ($\rho = 0.5$). These habitat factors relate to stream size, light, and basin morphology. In addition, the relative abundance of biraphid forms also decreased with increasing stream length ($\rho = -0.54$) but increased with basin slope ($\rho = 0.57$, $p < 0.01$). In contrast to Molloy's results (1992), stalked forms decreased in abundance as average velocity of the reach increased ($\rho = -0.56$) in benchmark streams. The Molloy guild *Cocconeis* spp. increased in relative abundance as the average riffle velocity increased ($\rho = 0.51$). *Cocconeis placentula* was described by Kelly and others (1995) as being firmly attached to the substratum, and therefore able to live in areas of swift flow.

A variety of algal metrics also correlated with basin-, segment-, and reach-level habitat characteristics (table 8). Similarly, Leland (1995) found scale to play an important role in evaluating the effects of environmental variables on benthic algae. Total abundance of all algae increased ($\rho = 0.56$, $p < 0.01$) with drainage area, meaning the larger the drainage area, the more algal cells found at the site. This finding is in agreement with the general idea that productivity increases from small headwater streams to larger streams in a general longitudinal stream gradient or continuum (Vannote and others, 1980). Total abundance also increased with percent riffle ($\rho = 0.50$) but decreased with percent run ($\rho = -0.60$, $p < 0.01$) in the reach. Pollution-tolerant diatoms had lower relative abundance in streams with higher basin soil permeability ($\rho = -0.65$, $p < 0.01$) and average reach velocity ($\rho = -0.49$). Similarly, Bahls' index of biological integrity increased, indicating less impairment, as the average riffle velocity increased ($\rho = 0.62$, $p < 0.01$). Abundance of diatom cells and taxa was positively related to many habitat characteristics ($\rho = 0.5$), including basin drainage density, drainage area, Q/Q2, stream length, and average width of natural riparian vegetation. This again agrees with the findings of Molloy (1992) that the number of diatom taxa increased with stream size. Nitrogen-fixing algae, most of which were blue-green algae, were more abundant in streams with greater erodibility, sinuosity, and percent riffle. These are characteristics of headwater streams.

Several diatom guilds and algal metrics were found to be related to land use (table 9). Centric forms increased in abundance in streams with higher percentages of agricultural land ($\rho = 0.58$, $p < 0.01$) and lower percentages of forested land ($\rho = -0.50$), and adnate forms also followed this pattern. The distribution of *Achnanthes* spp. was directly opposite to that of centric and adnate forms. Algal taxa richness decreased with higher percentages of agricultural land and lower percentages of forested land. The relative abundance of pollution-tolerant diatoms was higher in streams where the land use was primarily agricultural compared to streams with primarily forested land in the basin. These results indicate a shift in algal-community structure with a shift in land use from forest to agriculture. Higher percentages of grassland, a category that includes pasture, were related to decreased relative abundance of filamentous and stalked forms of diatoms and increased abundances of erect forms; however, the percentage of pollution-tolerant diatoms decreased as the percentage of grassland increased ($\rho = -0.62$, $p < 0.01$). More diatom taxa were found in basins with greater wetland area ($\rho = 0.54$).

The type of surficial deposits was a characteristic used to delineate RHU's that appeared to be an important factor for some algal taxa. Shannon-Wiener diversity indexes for diatoms were significantly higher in RHU 3 than in RHU 1. Although carbonate bedrock is found in both RHU's, RHU 3 contains sandy surficial deposits whereas RHU 1 contains clayey surficial deposits. Kruskal-Wallis and Tukey test results showed that basins with sandy surficial deposits had higher diatom diversity than basins with clayey deposits. The relative abundances of nitrogen fixers, blue-green algae, and three Molloy diatom guilds (centric, filamentous, and stalked) were significantly higher in sandy deposits than in sandy/sand-and-gravel deposits. Sandy/sand-and-gravel deposits were related to greater relative abundances of diatoms and the Molloy guild *Achnanthes* spp. when compared to deposits that were primarily sandy. Although the surficial deposits for RHU 3 are considered primarily sandy, this category also included silt, which may explain some of the differences found between RHU 3 and RHU 1.

Bedrock type, another characteristic used to delineate RHU's, also was found to be related to the distribution of some benthic algae. The relative abundance of diatom cells and *Achnanthes* spp. was higher in stream basins with igneous/metamorphic bedrock than in stream basins with carbonate bedrock; however, the

Table 8. Spearman-rank correlations (rho) between algal metrics and habitat characteristics for 20 agricultural benchmark streams in the Western Lake Michigan Drainages study unit, 1993

[Algal metrics are for richest-targeted habitat samples. Correlations are shown with Spearman rho $\geq$ 0.5 and $p < 0.05$; *$p < 0.01$, **$p < 0.001$; --, no significant correlation; n = 20 sites, except that correlations with percent riffle, pool, and run are for 19 sites; no data were available for these three characteristics at Smith Creek; average width of natural riparian vegetation is for segment; cells/cm^2, algal cells per square centimeter (cm^2); % algal metric, algal cells as percent of total algal cells per cm^2 except that percent pollution-sensitive or tolerant diatoms as percent of total diatom cells per cm^2; %, percent; m, meters; km, kilometers; km/km^2, kilmeters per square kilometer; in/hr, inches per hour; ft/s, feet per second]

Habitat characteristic	Algal metric								
	Total abundance (cells/cm^2)	Bahls' Index of Biological Integrity[1]	Bahls' pollution index[2]	Pollution sensitive diatoms (%)	Pollution tolerant diatoms (%)	Nitrogen-fixing algae (% cells/cm^2)	Blue-green algae (% cells/cm^2)	Diatoms (% cells/cm^2)	Diatoms (% taxa/cm^2)
Basin drainage density (km/km^2)	--	--	--	--	--	--	--	--	.51
Basin relief (m)	--	--	0.46	--	--	--	--	--	--
Permeability (in/hr)	--	--	--	--	-0.65*	--	--	--	--
Erodibility factor	--	--	--	--	--	.45	--	--	--
Drainage area (km^2)	0.56*	--	.52	0.46	--	--	--	--	--
Basin slope (m/km)	--	--	--	--	--	--	--	--	-0.53
Q/Q2 (%)	--	--	--	--	--	-.56	-0.54	0.54	
Stream length (km)	--	--	.45	--	--	--	--	--	.49
Cumulative stream length (km)	--	--	--	--	--	--	--	--	.51
Sinuosity	--	--	--	--	--	.52	--	--	.50
Average width of natural riparian vegetation (m)	--	--	--	--	--	--	-.51	.52	.52
Riffle in reach (%)	.50	--	--	--	--	.54	--	--	--
Run in reach (%)	-.60*	--	--	--	--	--	--	--	--
Average velocity of reach (ft/s)	--	--	.57*	--	-.49	--	--	--	--
Average velocity of riffles (ft/s)	--	.62*	--	--	--	--	--	--	--
Average embeddedness of riffles (%)	--	--	--	--	--	--	.46	-.45	--

[1]From Bahls (1993).

[2]From Bahls (1993).

Table 9. Spearman-rank correlations (rho) between percent relative abundance of Molloy diatom guilds, algal metrics, and land use for 20 agricultural benchmark streams in the Western Lake Michigan Drainages study unit, 1993

[Diatom guilds are based on data for richest-targeted habitat samples and morphological guilds from Molloy (1992). Algal metrics are for richest-targeted habitat samples except for taxa richness (RTH/QMH) which is for the combined richest targeted (RTH) and qualitative multihabitat (QMH) samples. Land-use information is from WISCLAND (Wisconsin Initiative for Statewide Cooperation on Landscape Analysis and Data) statewide satellite-derived land cover data (Lillesand and others, 1998). Correlations are shown with Spearman rho (r) $\geq$ 0.4 and $p < 0.05$; *$p < 0.01$, **$p < 0.001$, -- no significant correlation; n = 20 sites]

Molloy diatom guild and algal metric	Land use (%)			
	Agricultural	Grassland	Forested	Wetland
Molloy diatom guild				
Achnanthes spp. (%)	-0.54	--	0.51	--
Centric forms (%)	.58*	--	-.50	--
Filamentous forms (%)	--	-0.48	--	--
Adnate forms (%)	.45	--	-.56	--
Erect forms (%)	--	.53	--	--
Stalked forms (%)	--	-.54	--	--
Algal metric				
Taxa richness (RTH)	-.45	--	--	--
Taxa richness (RTH/QMH)	-.51	--	.54	--
Diatoms (% taxa)	--	--	--	.54
Pollution tolerant diatoms (%)	--	-.62*	--	--

relative abundance of nitrogen-fixing and blue-green algae was reversed from this pattern. The percentage of diatom taxa was higher in igneous/metamorphic bedrock basins than in sandstone but not carbonate bedrock basins. Igneous/metamorphic and carbonate bedrock basins contained greater percentages of pollution-tolerant diatoms than sandstone bedrock basins. Centric diatoms were more abundant in carbonate bedrock streams than in streams with either igneous/metamorphic or sandstone bedrock; erect forms were more abundant in streams with igneous/metamorphic bedrock than in streams with the other two bedrock types. Together with the results for surficial deposits, these results for bedrock indicate that RHU's and the components used to delineate them are valuable in understanding the abundance and distribution of benthic algae in these benchmark streams.

As discussed above, several significant differences were found for various algal metrics, especially those for diatoms, among RHU's and (or) factors used to delineate RHU's (land use, surficial deposits, and bedrock). The percent relative abundances of nitrogen-fixing and blue-green algae were significantly higher in RHU 3 than in RHU 20. In contrast, the percent relative abundances of diatoms and Molloy diatom guild *Achnanthes* spp. were significantly higher in RHU 20 than in RHU 3. These results indicate that streams in RHU 3 are more nitrogen limited than streams in RHU 20 but relations between abundances of these algal types and nitrogen concentrations were not significant. The percentage of diatom taxa in RHU 20 was greater than in RHU's 1 and 26. The relative abundance of erect forms of diatoms in RHU 26 was larger than in RHU's 20 and 1. In addition, percentages of pollution-tolerant diatoms were lower in RHU 26 than in the more southern RHU 20.

Significant relations between algal metrics and Molloy diatom guilds were found among ecoregions. The relative abundance of blue-green algae was higher in the Southeastern Wisconsin Till Plains ecoregion than in the North Central Hardwood Forests ecoregion, as was the diatom silt index and the relative abundance of Molloy diatom guilds for centric, filamentous, and stalked forms. The relative abundances of diatoms, erect diatom forms, and pollution-sensitive diatoms, and the pollution index (higher values indicate better water quality) was higher in the latter ecoregion. These results indicate that water quality in sampled streams from the North Central Hardwood Forests may be less degraded than in streams from the Southeastern Wisconsin Till Plains ecoregion.

Water Chemistry

Significant correlations were observed between algal-community metrics and most chemical water-quality measures at benchmark streams (table 10). A decrease in algal taxa richness corresponded to an increase in specific conductance ($\rho = -0.64$, $p < .01$, $\rho = -0.56$, $p < .01$) and concentrations of dissolved nitrate-plus-nitrite nitrogen ($\rho = -0.61$, $p < .01$, $\rho = -0.60$, $p < .01$). Similar relations with taxa richness were found as the percentage of agricultural land increased in benchmark stream basins. Fitzpatrick and others (1996) found that specific conductance and concentrations of dissolved nitrate-plus-nitrite nitrogen increased with the percentage agricultural land in the basin. Taxa richness for RTH samples also decreased as the concentration of suspended sediment increased ($\rho = -0.55$). These results indicate that an increase in agricultural activities in a basin may have a negative effect on the number of algal species in benchmark streams. Increased relative abundance of pollution-tolerant diatoms (Lange-Bertalot, 1979) corresponded to increased concentration of nutrients (dissolved nitrate-plus-nitrite nitrogen, dissolved ammonium nitrogen, total phosphorus) and fine sediment (suspended sediment and percent fines < 0.062 mm). This relation also was found in benchmark streams where the basin was primarily agricultural compared to streams with primarily forested basins. As Bahls' pollution index decreased, indicating more pollution, increases were seen for specific conductance ($\rho = -0.47$) and the concentration of total phosphorus ($\rho = -0.53$) and suspended sediment ($\rho = -0.55$). On the contrary, the relative abundance of pollution-sensitive diatoms (Lange-Bertalot, 1979) decreased as specific conductance ($\rho = -0.46$) and the concentration of suspended sediment ($\rho = -0.44$) increased. Similarly, Bahls' index of biological integrity decreased, indicating greater impairment with increases in concentration of suspended sediment ($\rho = -0.65$, $p < .01$). These relations indicate that diatom assemblages shift from pollution sensitive to pollution tolerant and that streams become more impaired as the percentage of agriculture increases in the basin. The percentage of diatom taxa decreased with increases in concentration of dissolved nitrate-plus-nitrite nitrogen ($\rho = -0.60$), but increased with the increase in total organic-plus-ammonia nitrogen ($\rho = 0.61$, $p <.01$), total phosphorus ($\rho = 0.47$) and percent fines <.062 mm ($\rho = 0.54$). Similar trends were observed between dissolved and particulate nutrients and stream productivity in Midwestern streams. Porter (2000) found that concentrations of dissolved nitrate-plus-nitrite nitrogen and orthophosphate decreased significantly with increases in stream productivity, which is probably associated with algal uptake of dissolved nutrients. In that study, the concentrations of chlorophyll *a* for seston were positively correlated with concentrations of suspended organic carbon, total organic nitrogen, particulate phosphorus, and total suspended sediment, an indication that total nutrient and organic enrichment in Midwestern streams is reflected by large populations of algal seston. Organic enrichment resulted in high biological oxygen demand (BOD) due to increased concentrations of naturally occurring organic compounds. In the benchmark stream study, the relative abundance of blue-green algal cells increased with pH ($\rho = 0.49$), whereas the relative abundance of diatom cells decreased. Pan and others (1996) found that algal assemblages shifted from dominance by diatoms to dominance by blue-greens with the input of excessive phosphorus. Both high pH and high phosphorus concentrations may act as surrogates for agricultural activities taking place in the benchmark stream basins. Similarly, pH increased ($\rho = 0.45$), with the increase in total abundance of all algae cells, again indicating that productivity may be related to agricultural activities. On the other hand, the total abundance of all algal cells decreased as suspended sediment increased ($\rho = -0.64$, $p <.01$). In this case, the nutrients may be tied up in the suspended sediment and unavailable for algal growth.

Numerous relations between diatom guilds and water-quality measures also were observed (table 11). The relative abundance of diatom guild *Eunotia* spp. (Molloy, 1992) increased as pH ($\rho = -0.54$, $p <.01$), specific conductance ($\rho = -0.68$, $p <.001$) and nitrate-plus-nitrite nitrogen ($\rho = -0.48$) decreased, and was positively correlated with the concentration of dissolved ammonium (NH_4-N) ($\rho = 0.46$). Similarly, Kelly and others (1995) described *Eunotia exigua* to be a dominant species in clean, low-pH water. Pan and others (1996) found that diatom-species composition shifted along a pH gradient and identified numerous species of *Eunotia* as being most abundant at low pH sites. Numerous studies have found pH and specific conductance to be positively correlated; for example Kelly and Whitton (1995). Similar to *Eunotia* spp., the

Table 10. Spearman-rank correlations (rho) between algal metrics and chemical and physical characteristics for 20 agricultural benchmark streams in the Western Lake Michigan Drainages study unit, 1993

[Algal metrics are for richest-targeted habitat samples except for taxa richness (RTH, QMH) which is for the combined richest-targeted (RTH) and qualitative multi-habitat (QMH) samples; cells/cm^2, algal cells per square centimeter; Index of biological integrity according to Bahls (1993) and calibrated for the Western Lake Michigan Drainages; %, algal cells or taxa by division as percent total algal cells per cm^2 or taxa except that percent pollution-sensitive or tolerant diatoms per cm^2 as percent of total diatom cells per cm^2. Correlations are shown with Spearman rho $\geq$ 0.5 and $p < 0.05$, *$p < 0.01$, **$p < 0.001$; --, no significant correlation]

Chemical and physical characteristics	Algal metric									
	Total abundance (cells/cm^2)	Taxa richness RTH	Taxa richness (RTH, QMH)	Bahls' Index of Biological Integrity	Bahls' pollution index	Pollution-sensitive diatoms (%)	Pollution-tolerant diatoms (%)	Blue-green algae (% cells/cm^2)	Diatoms (% cells/cm^2)	Diatoms (% taxa/cm^2)
pH	0.45	--	--	--	--	--	--	0.49	-0.48	--
Specific conductance (µS/cm)	--	-0.64	-0.56*	--	-0.47	-0.46	--	--	--	--
Total organic plus ammonia nitrogen (mg/L as N)	--	--	--	--	--	--	--	--	--	0.61*
Nitrate plus nitrite, dissolved (mg/L as N)	--	-.61*	-.60*	--	--	--	0.51	--	--	-.60*
Ammonium, dissolved (mg/L as N)	--	--	--	--	--	--	.58*	--	--	--
Total phosphorus (mg/L as P)	--	--	--	--	-.53	--	.61*	--	--	.47
Suspended sediment (mg/L)	-.64*	-.55	--	-.65*	-.55	-.44	.45	--	--	--
% fines (< .062 mm)	--	--	--	--	--	--	.78**	--	--	.54

Table 11. Spearman-rank correlations (rho) between percent relative abundance of Molloy diatom guilds and chemical and physical characteristics for 20 agricultural benchmark streams in the Western Lake Michigan Drainages study unit, 1993

[Diatom guilds are based on data for richest-targeted habitat samples and morphological guilds from Molloy (1992). Correlations are shown with Spearman rho $\geq$ 0.5 and $p < 0.05$, *$p < 0.01$, **$p < 0.001$; --, no significant correlation; %, diatom cells per square centimeter (cm^2) in specified Molloy guild as percent of total diatom cells per cm^2]

Chemical and physical characteristics	Molloy diatom guild						
	Achnanthes spp.	Centric forms	Adnate forms	Erect forms	Biraphid/ prostrate/ nonmotile forms	Stalked forms	*Eunotia* spp.
pH	--	--	--	--	-0.56*	--	-0.54*
Specific conductance (µS/cm)	-0.48	0.59*	--	--	--	--	-.68**
Nitrate plus nitrite, dissolved (mg/L as N)	--	--	--	--	--	--	-.48
Ammonium, dissolved (mg/L as N)	--	--	--	--	--	--	.47
Dissolved orthophosphate (mg/L as P)	--	--	0.46	--	--	--	--
Suspended sediment (mg/L)	--	--	--	-.63*	--	--	--
% fines (< 0.062 mm)	--	--	--	--	--	.52	--

relative abundance of the biraphid/prostrate nonmotile growth-form guild also increased as pH decreased (ρ = -0.56, p <.01). The relative abundance of A*chnanthes* spp. also increased as specific conductance decreased (ρ = -0.48). Kutka and Richards (1996) found *Achnanthes* spp. to be associated with a high pollution index, indicating that they are generally associated with less-degraded water. In this study, the relative abundance of *Achnanthes* spp. increased with the percentage of forested land but decreased with increases in agricultural land. Both *Eunotia* spp. and *Achnanthes* spp. tend to occur in headwater assemblages (Molloy, 1992). On the other hand, the relative abundance of the centric growth-form guild increased with specific conductance (ρ = 0.59, p < 0.01) and the relative abundance of adnate forms increased with concentrations of dissolved orthophosphate (ρ = 0.46). Similar relations were found as the percentage agricultural land increased in benchmark stream basins. According to Molloy (1992), the centric forms are traditionally considered plankters and are commonly found in deep, large, slow-moving streams. The relative abundance of erect forms increased with the percentage of grassland and decreased as the concentration of suspended sediment increased (ρ = -0.63, p < .01). To the contrary, the relative abundance of stalked forms decreased as the percentage of grassland increased and increased with the percent fines < 0.062 mm transported in stream water. It would appear that erect forms are more sensitive to sediment than stalked forms and that erect forms prefer streams in basins dominated by grassland land cover. Increasing percentages of grassland were significantly related to increasing permeability (ρ = 0.74) and velocity (ρ = 0.60), as well as decreasing total phosphorus concentrations (ρ = -0.49), percentages of fines (ρ = -0.50), and erodibility (ρ = -0.59). The greater permeability in grassland may result in increased input of ground water to streams. Results indicate that grassland in the basin provides a more favorable habitat for erect than stalked diatom forms.

Multivariate Analyses with Habitat and Water Chemistry Variables

TWINSPAN analyses of the RTH relative abundance data revealed site groups, generally by RHU, but did not show groupings by ecoregion (fig. 4). Group A included only sites from RHU 1: Hibbard, Krok, and Little Scarboro Creeks. *Gomphonema olivaceoides hutchinsoniana* was found at only these three sites. Group B included mostly RHU 3 and RHU 26 sites, and this group displayed a further division into groups B1 and B2, though these two groups were similar. Group B1 included all of the RHU 3 sites (East Branch Milwaukee River, Nichols Creek, Mullet River, and Watercress Creek) and two sites from RHU 26 (Pine River and Willow Creek). Group B2 included the remainder of the RHU 26 sites (Chaffee Creek, Lawrence Creek, Mecan River, Neenah Creek) and two sites from RHU 1 (Casco and Tisch Mills Creeks). Group C included all sites from RHU 20 and no others. The pollution sensitive *Achnanthes minutissimum* was more abundant at group B2 sites than at group B1 sites and more abundant at group C sites than at group B2 sites. *Navicula cryptocephala veneta* (Bahls = "less tolerant" to Lange-Bertalot = "sensitive") and *Fragilaria pinnata lancettula* (sensitive) were found more commonly at group B2 sites than at group B1 sites. Group C sites were segregated at the first TWINSPAN division, and the main indicator species was *Navicula tantula*, a diatom that was found in RTH samples only at these sites. *Navicula tantula* is listed as "less tolerant" to pollution by Bahls (1993). *Eunotia naegelii* and *Stauroneis kriegeri* also were found only at group C sites, and these sites as a group also had more *Achnanthes helvetica*, an unidentified blue-green alga, *Frustulia rhomboides amphipleuroides*, and *Oscillatoria* sp. 1 than did group B sites. TWINSPAN site groupings were less clear when guilds were used instead of species; however, five of six sites in RHU 20 still formed a distinct grouping, and these were the only sites to have taxa in the Molloy guild *Eunotia* spp.

Detrended correspondence analysis (DCA) ordination of 58 algal species also displayed groupings by RHU for most sites (fig. 5). The first two DCA axes explained the greatest variation in the distribution and abundance of benthic algae. The eigenvalues for DCA axes 1 through 4 were 0.1850, 0.1409, 0.0735, and 0.0412, respectively. The percentage of riffles in the reach, pH, erodibility, specific conductance, and average channel width to depth ratio were negatively correlated with DCA axis 1 scores, whereas average width of natural riparian vegetation (segment scale), Q/Q2, drainage density, and the percentage of wetland in the basin were positively correlated with axis 1 scores. DCA Axis 2 was positively correlated with the percentage of agriculture in the basin and negatively correlated with the percentage of grassland in the basin, average reach velocity, and permeability. These results indicate that these are the major factors influencing the overall

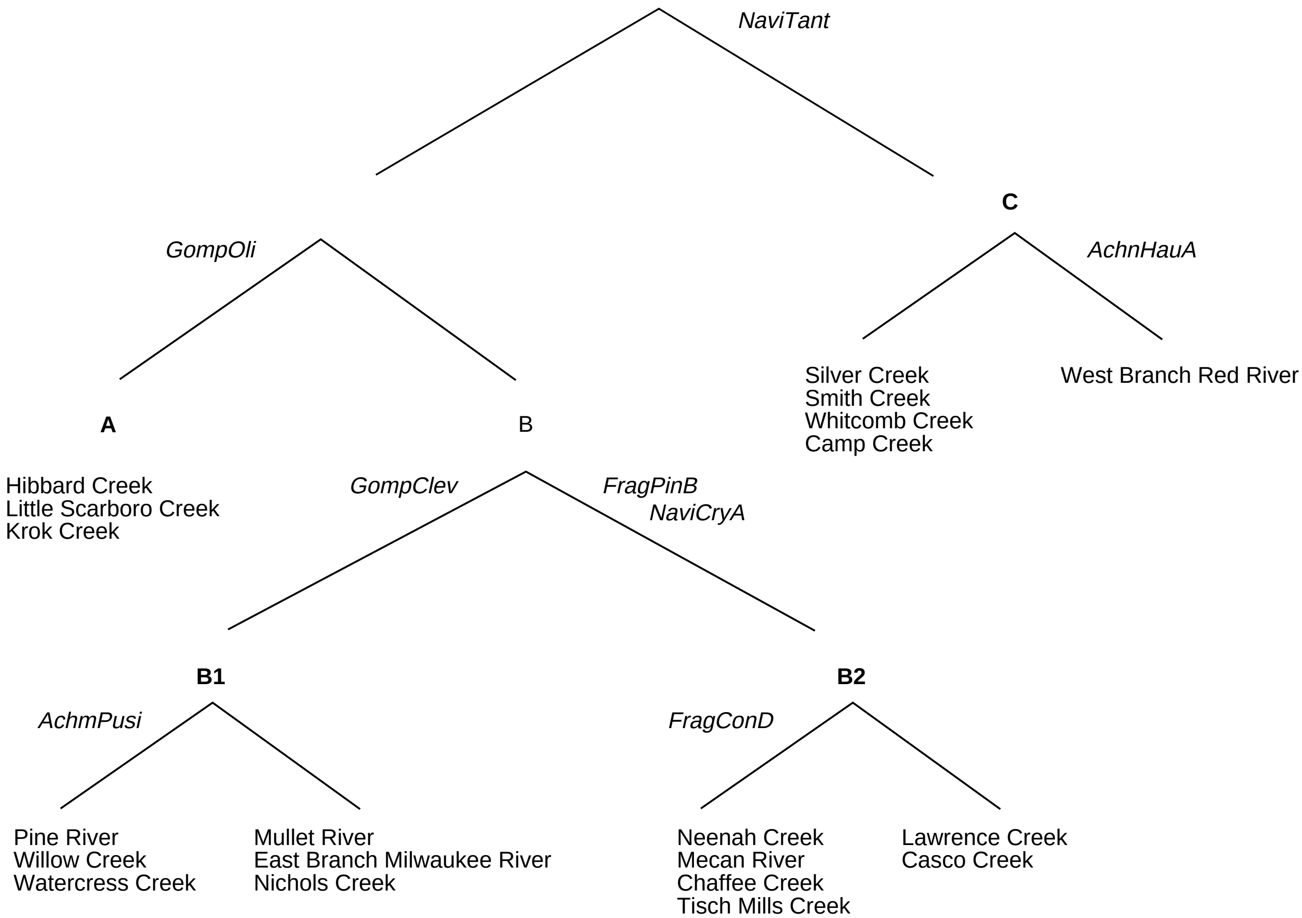


Figure 4. Two-way indicator species analyses (TWINSPAN) results for site groupings based on algal relative abundance data for all taxa from 20 agricultural benchmark streams in agricultural areas of eastern Wisconsin, Western Lake Michigan Drainages study unit, 1993. (Data were percentage transformed. At each level, the "indicator" species code names for the division are shown in italics; full scientific names are listed in appendix 1.)

abundance and distribution of benthic algae in the benchmark streams. As was found with TWINSPAN, RHU 20 sites separated out as a group from the remainder of sampled sites, especially those in RHU 3. RHU 3 and RHU 20 sites were divided from each other with respect to axis 1 factors, and algal communities from RHU 20 sites primarily reflected generally wider areas of natural riparian vegetation (segment scale), higher Q/Q2, lower pH, lower erodibility, and fewer riffles when compared to RHU 3 sites. RHU 26 sites grouped to some degree along axis 1 but were distributed along a wide gradient on Axis 2. RHU 1 sites Casco, Tisch Mills, and Krok Creeks were divided from the other RHU 1 sites, Little Scarboro and Hibbard Creeks, along Axis 2 because of lower percentages of grassland in the basin and lower average reach velocity at these first three creeks. With the exception of Lawrence, Little Scarboro, and Hibbard Creeks, the DCA ordination separated streams in the Southeastern Wisconsin Till Plains ecoregion (RHU's 1 and 3) from the North Central Hardwood Forests ecoregion (RHU 20 and 26).

Canonical correspondence analysis (CCA) results were similar to those for DCA. The eigenvalues for the first four CCA axes were 0.174, 0.146, 0.095, and 0.076. The first four axes explained 42.5 of the cumulative percentage variance of the species data and 67.7 of the cumulative percentage variance of the species-environment relation. All variable inflation factors were less than eight and there was no significant covariance among variables used in the analysis. Because erodibility and specific conductance were highly correlated (Pearson correlations $\geq$0.85) with the percentage of agriculture in the basin, the percentage of agriculture was selected as the representative variable for CCA.

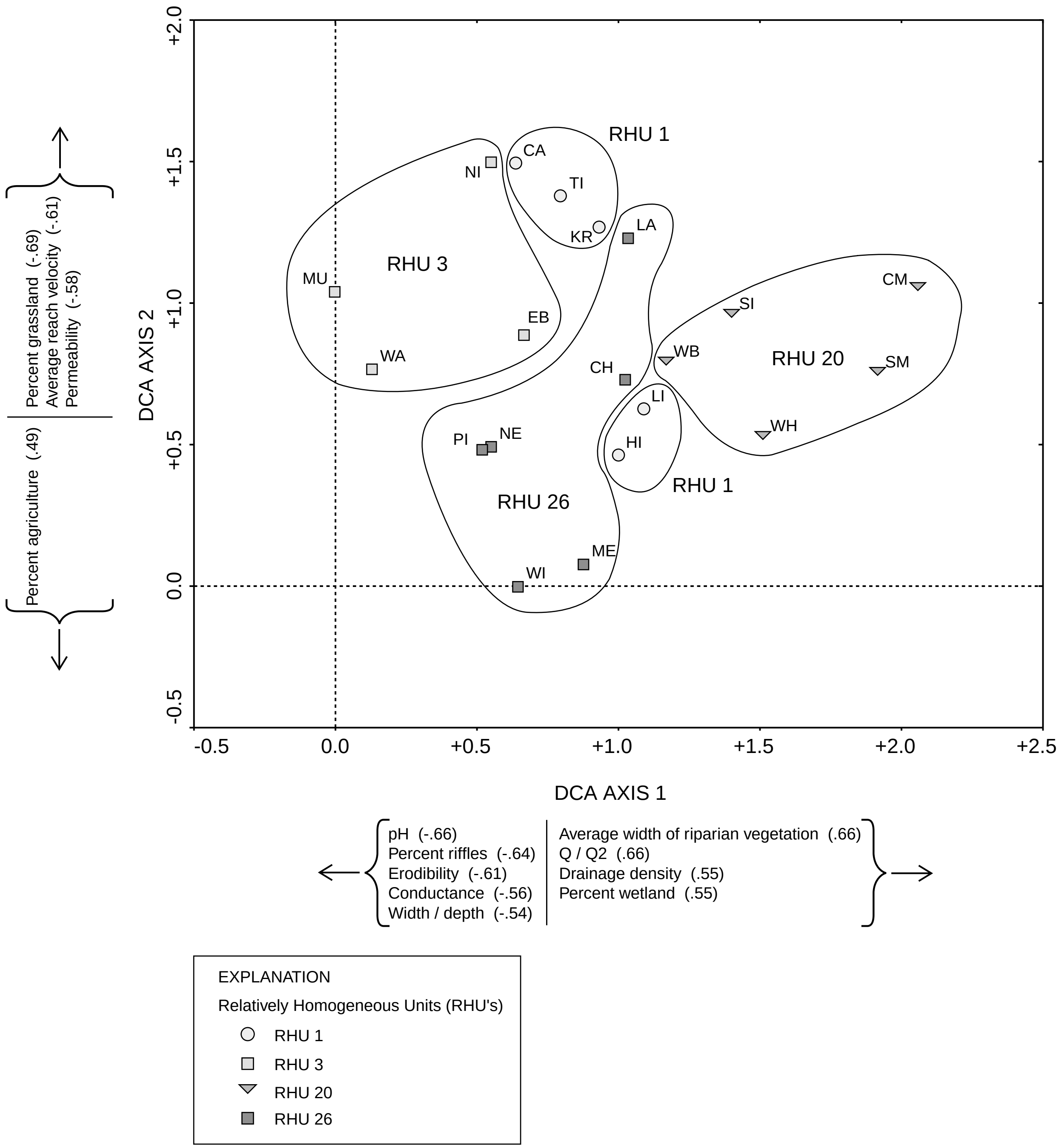


Figure 5. Patterns in algal communities shown by detrended correspondence analysis (DCA) ordination of 58 algal species for 20 agricultural benchmark streams in the Western Lake Michigan Drainages study unit, 1993. (Grouping by relatively homogeneous unit (RHU) is marked. For full stream names refer to table 1. Numbers in parentheses are Pearson correlations of the environmental variable to DCA axis 1 or 2.)

Permeability and grassland were highly correlated (Pearson correlation of 0.77), and grassland was selected as the representative variable for CCA. Values for pH were highly correlated (Pearson correlations $\geq$0.69) with percent riffles and the width/depth ratio, and pH was selected to represent these variables in CCA. The results of the Monte Carlo test indicated that all canonical axes were statistically significant ($p = 0.005$), showing that the relation between the species and the selected environmental variables was highly significant.

The most important environmental variables indicated by CCA, in order, were pH, average width of natural riparian vegetation (segment scale), percent wetland in the basin, percent agriculture in the basin, Q/Q2, and percent grassland in the basin (fig. 6). CCA showed that additional important factors in algal abundance and distribution were average reach velocity, relief, total phosphorus, and drainage density. In general, the longer the arrow representing an environmental variable, the more important the variable is with regard to species distributions (Ter Braak, 1986). As was found with DCA, RHU 20 sites were separated from RHU 3 sites and were most related to a greater average width of natural riparian vegetation (segment scale). The RHU 26 sites, with the exception of Lawrence Creek, grouped together in the CCA ordination on the basis of percentage of grassland in the basin, average reach velocity, and relief. The RHU 1 sites, Tisch Mills, Krok, and Casco Creeks, were separated from Little Scarboro and Hibbard Creeks. All of the RHU 3 sites were grouped together in the ordination, mostly on the basis of higher pH, a higher percentage of agriculture, and higher ortho-phosphorus concentrations. Ecoregion divisions in the ordination plot were not distinct; however, most sites from the Southeastern Wisconsin Till Plains ecoregion were associated with higher pH and higher percentages of agriculture in the basin. These sites tended to group to the lower left quadrant of the ordination plot. Most sites from the North Central Hardwood Forests ecoregion grouped toward the upper half of the ordination plot.

Algal species highly associated with increasing pH were the diatoms *Diatoma vulgare* and *Gomphonema olivaceum*, and the nitrogen-fixing blue-green alga *Calothrix parietina* (fig. 7). The abundance and distribution of diatoms *Achnanthidium affine*, *Nitzschia frustulum perminuta*, *Nizschia dissipata*, *Frustulia vulgaris* and *Navicula tantula* were most related to greater widths of natural riparian vegetation along streams. Diatoms *Cyclotella meneghiniana, Melosira varians, Navicula salinarum intermedia,* and *Fragilaria vaucheriae* were associated with the highest percentages of agriculture in stream basins.

SUITABILITY OF STUDIED STREAM REACHES AS BENCHMARK SITES

Most of the streams selected as potential benchmark sites in this study had healthy benthic algal communities, indicative of good to excellent water quality. Our results indicate that these streams can be compared accurately to other streams within the same ecoregion and (or) RHU, and used as benchmarks for restoration of streams affected by agriculture. Several measures of community "health" of benthic algal communities should be used to ensure that all important aspects are considered; however, the metrics associated with diatoms currently show the most promise in classifying water-quality conditions among sites.

The largest number of taxa at benchmark streams were represented by diatoms. It is generally accepted that a degradation in water quality results in changes to the algal community such that diatom taxa are less numerous and other groups of algae dominate. A dominance of blue-green algal cells at many of the benchmark streams is not of concern where that dominance was primarily due to one species of nitrogen-fixing algae, *Calothrix parietina*, and codominance by a pollution-sensitive diatom, *Achnanthidium minutissimum*. Dominance by these two algal species may be useful indicators for comparison in evaluating other streams in these areas of Wisconsin but should be considered as part of other supporting lines of evidence. The presence of the red alga *Audouinella hermanii* in more than half of the benchmark streams supports assignment of water quality in those streams where it occurs as good; however, *A. hermanii* was found at some streams where other algal metrics indicated minor water-quality concerns. It is not known why this red alga was absent from all but one of the RHU 20 streams.

Algal communities in the Mullet River, Nichols Creek, and Watercress Creek in RHU 1 showed evidence of minor stress with regard to diatom siltation and (or) pollution indexes. However, the overall biotic index was "good" in these streams and *C. parietina* was dominant. This combination of factors indicates that these streams might be used cautiously as benchmark streams. Little Scarboro Creek appears to be in

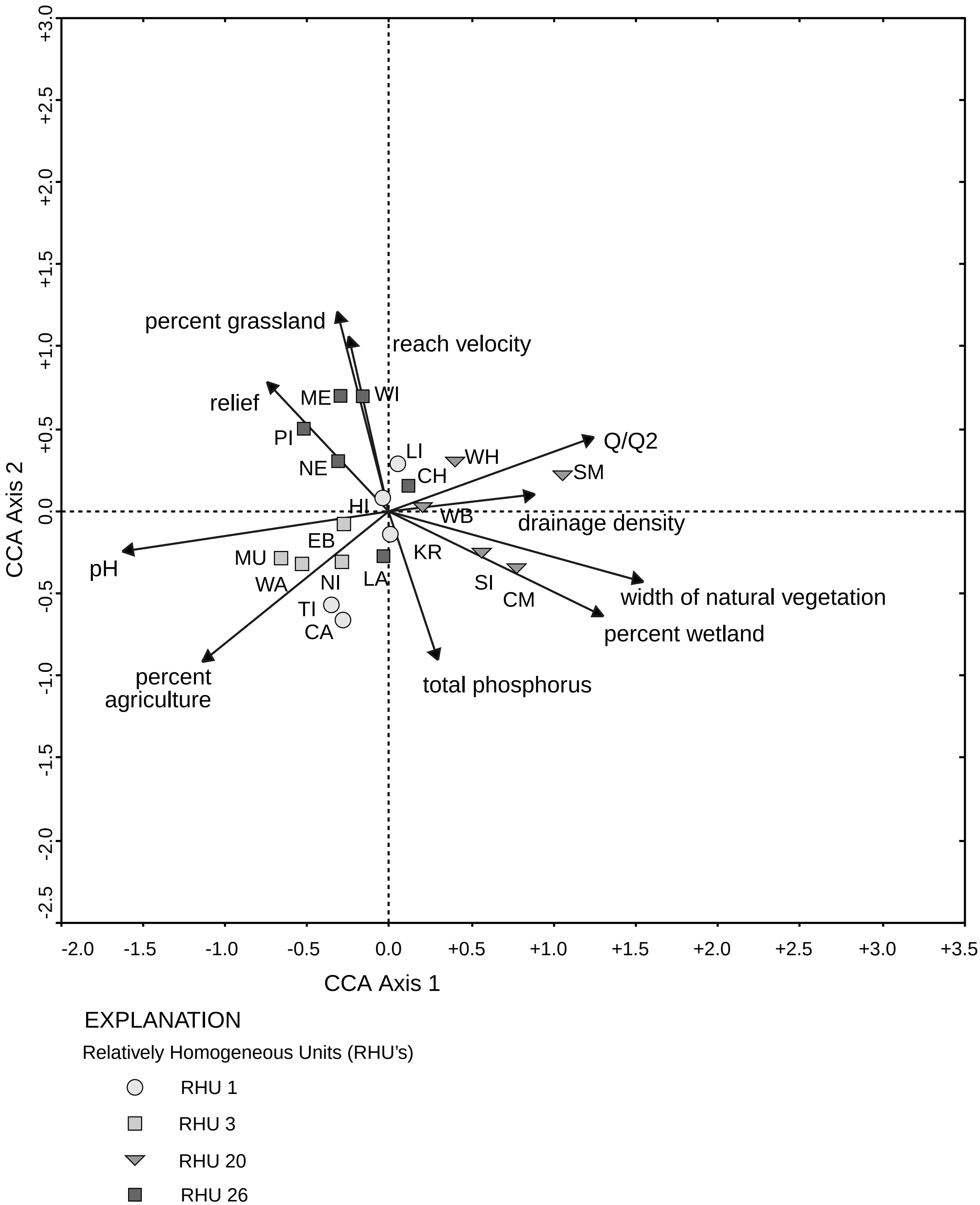
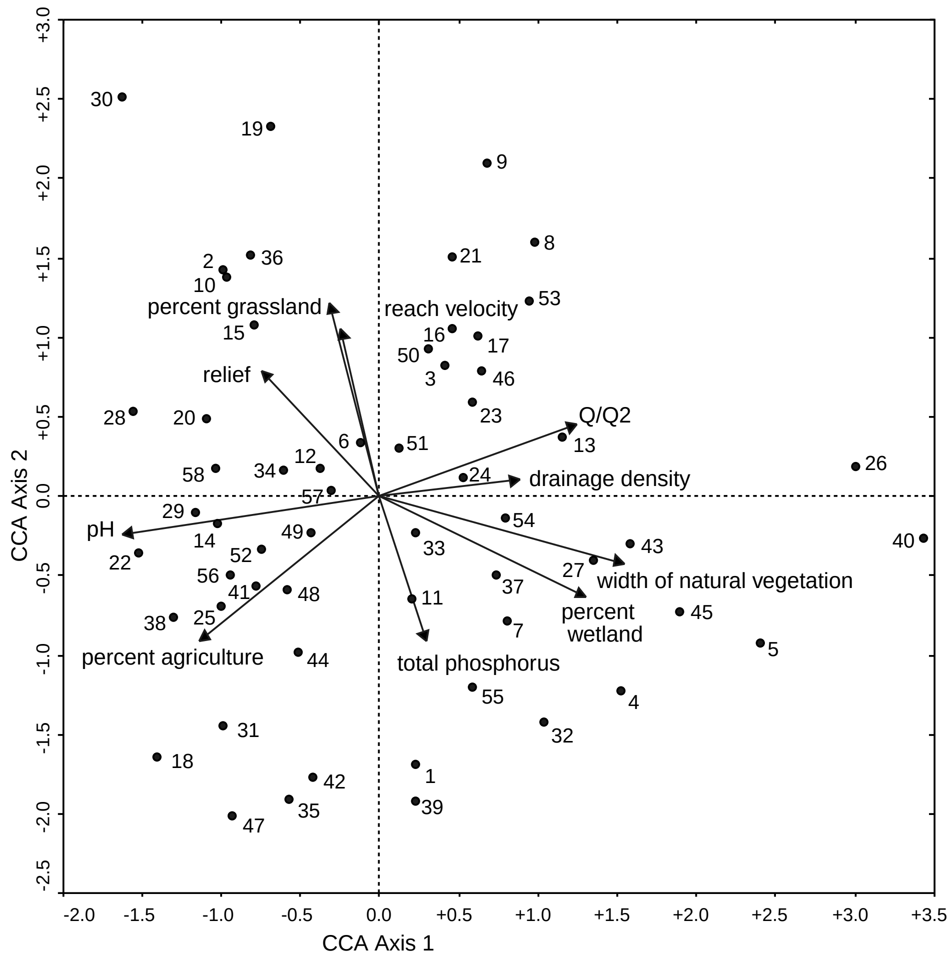


Figure 6. Patterns in site/environmental variable relations shown by canonical correspondence analysis (CCA) ordination for 20 agricultural benchmark streams in the Western Lake Michigan Drainages study unit, 1993. (For full stream names refer to table 1.)



EXPLANATION

Algal species

1 Achn Cons	20 Cymb Cist	39 Navi Secr
2 Achn Defl	21 Cyni Dilu	40 Navi Tant
3 Achn Laue	22 Diat Vulg	41 Navi VirA
4 Achn Pinn	23 Frag ConD	42 Nitz Amph
5 Achm Affi	24 Frag PinB	43 Nitz Diss
6 Achm Clev	25 Frag Vauc	44 Nitz Friz
7 Achm Lanc	26 Frus RhoA	45 Nitz FruA
8 Achm Pera	27 Frus Vulg	46 Nitz FruB
9 Achm Pusi	28 Gomp Clev	47 Nitz Kuet
10 Ampo Oval	29 Gomp Oliv	48 Nitz Line
11 Ampo OvaB	30 Hydr Breb	49 Nitz LinA
12 Audo Viol	31 Melo Vari	50 Pseu Brev
13 Calo Baci	32 Navi Cryp	51 Reim Sinu
14 Calx Pari	33 Navi CryA	52 Rhoi Abbr
15 Cocc Pedi	34 Navi Decu	53 Stau Cons
16 Cocc PlaB	35 Navi Lanc	54 Stau Lept
17 Cocc Thum	36 Navi Meni	55 Syne Rump
18 Cycl Mene	37 Navi Mini	56 Syne RumB
19 Cymb Affi	38 Navi SalA	57 Syne Ulna
		58 Syne UlnA

Figure 7. Patterns in species/environmental variable relations shown by canonical correspondence analysis (CCA) ordination for 20 agricultural benchmark streams in the Western Lake Michigan Drainages study unit, 1993. (Full scientific names of taxa are listed in appendix 1.)

comparatively good condition for a low-productivity first-order stream, but the siltation index was similar to that of Nichols and Watercress Creeks.

Krok Creek and Pine River, despite having the fewest algal taxa and low diatom diversities, still had other indicators suggesting these were good sites, such as a dominance of *C. parietina*, low siltation, and “good” ratings for the biotic index. At Whitcomb Creek, the dominance by blue-green algae that were not nitrogen fixers may not indicate stress when considered together with the high abundance (5.4 percent) of the red alga *A. hermanii* at this site and supporting algal metrics.

Based on results from our study, those streams least affected by anthropogenic impacts in the Southeastern Wisconsin Till Plains ecoregion were Tisch Mills and Hibbard Creeks in RHU 1 and the East Branch Milwaukee River in RHU 3. In the Northeastern Wisconsin Hardwood Forests ecoregion, those streams were the West Branch Red River and Silver Creek in RHU 20 and Lawrence and Chaffee Creeks in RHU 26. The biotic indexes were excellent for all of these streams except those in RHU 1, where no streams received excellent ratings. The East Branch Milwaukee River had the most algal taxa for all sites for the RTH and QMH samples combined, and Silver Creek had the most algal taxa of all streams for the RTH sample alone. Although *C. parietina* was absent from the Red River, *Achnanthidium minutissimum* was dominant and diatoms as a group were the dominant division of algae. Diatoms also were the dominant division at Chaffee and Lawrence Creeks, although the blue-green taxon *C. parietina* was the most abundant species of algae in these two streams.

SUMMARY

Samples of benthic algae were collected from 20 streams in the Western Lake Michigan Drainages in May and June of 1993 as part of the National Water-Quality Assessment program. The streams were selected from four agricultural areas (relatively homogeneous units, or RHU’s) with differing texture of surficial deposits and bedrock type as representative “benchmark” or reference streams that are minimally affected by human activities, especially agriculture. Two types of samples were collected from each stream: a quantitative sample from the richest targeted habitat (RTH) and a qualitative multi-habitat sample (QMH) of all habitats available in the stream reach. Analysis of the benthic algal data included (1) basic summary descriptions of the algal taxa at sites and comparison among sites, (2) comparison to established indexes, and (3) comparison of algal-community structure with selected habitat characteristics and environmental variables. Multivariate statistics, TWINSPAN, DCA, and CCA were used to identify important environmental factors affecting algal-community structure in the benchmark streams.

A total of 194 algal taxa were identified in the RTH samples and 264 taxa in QMH samples from the benchmark streams. Blue-green algal cells were the dominant algal division at 15 sites, and the dominant species at most of these sites was *Calothrix parietina*, a nitrogen-fixing blue-green alga typically found in pristine streams. The filamentous red alga, *Audouinella hermanii*, generally associated with relatively cool, clean, flowing water conditions, also was found at 11 of 20 sites. More than 90 percent of the taxa in benchmark streams were diatoms. The dominant morphological groups of diatoms (guilds) observed were the *Achnanthes* spp., erect forms, and *Navicula* spp.

The Shannon-Wiener diversity index for diatoms was high at most of the benchmark streams, indicating either minor stress or no stress on the diatom community. Diatom indexes for 17 of 20 benchmark streams indicated no pollution effects and no significant siltation. Bahls’ index of biological integrity for diatoms, based on these diversity, pollution, and siltation indexes, rated all benchmark streams good to excellent with either minor or no aquatic-life impairment.

A variety of algal metrics and the relative abundance of Molloy diatom guilds correlated with basin-, segment-, and reach-level habitat characteristics. Abundance of diatom cells or taxa was positively related to many habitat characteristics, including basin drainage density, drainage area, Q/Q2 (instantaneous discharge measured at time of sampling divided by the estimated 2-year flood discharge), stream length, and average width of natural riparian vegetation. Algal taxa richness decreased with higher percentages of agricultural land and lower percentages of forested land. The relative abundance of pollution-tolerant diatoms was higher in streams where the basin land use/cover was primarily agricultural as opposed to forested. Centric and adnate diatom forms increased in abundance in streams with greater percentages of agricultural land and lower percentages of forested land whereas the abundance of *Achnanthes* spp. was greater in streams dominated by forested land. Together, these results indicate changes in the algal community structure with increasing agriculture. The Shannon-Wiener diversity index for diatoms, the percentage of diatom taxa, and the relative percent abundances of diatom cells, pollution-tolerant diatoms, *Achnanthes* spp., erect diatom forms, nitrogen-fixing algae, and blue-green algae differed significantly among either RHU's or ecoregions. Higher abundances of pollution-sensitive diatoms and a higher pollution index indicate that water quality in streams from the North Central Hardwood Forests ecoregion may be less affected by human activities than water quality in streams of the Southeastern Wisconsin Till Plains ecoregion.

Algal-community metrics also were correlated with certain water-quality parameters at the benchmark streams. Algal taxa richness decreased as specific conductance, dissolved nitrate-plus-nitrite, and suspended sediment increased, suggesting a negative effect on the algal taxa richness of the stream by agricultural activities. Pollution-tolerant diatoms and the pollution index increased with agriculture intensity. Diatom assemblages appear to shift from pollution-sensitive to pollution-tolerant diatoms and streams become more impaired as agricultural activities increase in the basin. The Molloy guilds *Eunotia* spp., *Achnanthes* spp., and erect forms were more abundant in streams with minimal agricultural effects, whereas centric, adnate and stalked forms were more abundant in streams with substantial agricultural effects.

Multivariate analyses provided additional insight into the most important environmental factors affecting benthic algae at the 20 benchmark streams. TWINSPAN analyses of the RTH relative abundance data generally indicated groupings of sites by RHU but not by ecoregion. Results for DCA and CCA were similar but CCA is considered to be more powerful than DCA for detecting relationships between species composition and environmental factors. Although both analyses separated sites fairly well according to RHU, only DCA ordination indicated some separation relative to ecoregion. These results indicate that RHU's may be a more useful framework than ecoregions for interpreting benthic algal distributions in the Western Lake Michigan Drainages. Detrended correspondence analysis showed that the percentage of grassland in the basin, average width of natural riparian vegetation (segment scale), pH, Q/Q2, the percentage of riffles in the reach, erodibility, average reach velocity, permeability, specific conductance, the percentage of wetland and agriculture in the basin, and drainage density, and average channel width-to-depth ratio explained the greatest variation in algal-community structure. Canonical correspondence analysis indicated that pH, average width of natural riparian vegetation (segment scale), percent wetland in the basin, percent agriculture in the basin, Q/Q2, and percent grassland in the basin were the most important variables affecting the distribution and relative abundance of benthic algae. There is some overlap between important variables indicated by DCA and CCA. These results indicate that the variability in abundance and distribution of benthic algae in the benchmark streams was strongly related to reach, segment, and basin-level environmental variables, and it illustrates the importance of scale in evaluating the effects of environmental variables on benthic algae, a point also demonstrated by Leland (1995) and Cuffney and others (1997).

Of the 20 streams selected as potential benchmark sites in this study, 17 had "healthy" benthic algal communities indicative of good to excellent water quality. When possible, comparisons of these streams to other streams should be considered within the same RHU and/or ecoregion to be accurate as benchmarks for restoration of streams adversely affected by agriculture.

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APPENDIX

Appendix. Benthic algae found at 20 agricultural benchmark streams in the Western Lake Michigan Drainages study unit, 1993

[RHU, relatively homogeneous unit; Refer to table 1 for full stream names and locations. This taxonomic hierarchy is based on Bourrelly (1981, 1985, 1988, 1990) for soft algae, Taylor (1987) for dinoflagellates, and Round and others (1990) for diatoms. The taxonomy also included additional recent revisions for diatoms by Bukhtiyarova and Round (1996), Round and Bukhtiyarova (1996), Round and Basson (1997), Krammer (1997a,b), and Lange-Bertalot (1997).]

Code	Division	Class	Order	Taxonomic Name	Comments (alternate nomenclature)	RHU 1					RHU 3				RHU 20					RHU 26						Totals
						TI	KR	LI	CA	HI	EB	NI	MU	WA	WH	WB	SI	SM	CM	LA	NE	CH	ME	WI	PI	
	Bacillariophyta																									
		Bacillariophyceae																								
			Achnanthales																							
AchnCons				*Achnanthes conspicua*		x	x	x	x	x	x				x	x	x		x		x					11
AchnDeci				*Achnanthes decipiens*								x												x		2
AchnDefl				*Achnanthes deflexa*		x	x			x				x	x			x		x	x		x	x	x	11
AchnDeth				*Achnanthes detha*	*Psammothidium subatomoides*													x			x					2
AchnHauc				*Achnanthes hauckiana*	*Planothidium hauckianium*											x	x									2
AchnHauA				*Achnanthes hauckiana rostrata*		x			x		x		x	x		x		x								7
AchnHelv				*Achnanthes helvetica*			x	x		x							x	x	x							6
AchnLanA				*Achnanthes lanceolata abbreviata*						x							x	x	x							4
AchnLanB				*Achnanthes lanceolata apiculata*								x									x					2
AchnLanC				*Achnanthes lanceolata bimaculata*											x		x					x				3
AchnLaue				*Achnanthes lauenburgiana*						x	x		x	x	x	x	x	x	x			x	x	x		12
AchnLine				*Achnanthes linearis*																			x			1
AchnLinA				*Achnanthes linearis curta*																				x		1
AchnMicr				*Achnanthes microcephala*	*Achnanthidium microcephalum*						x				x											2
AchnPera				*Achnanthes peragalli parvula*												x	x		x		x					4
AchnPinn				*Achnanthes pinnata*		x	x	x		x			x	x	x	x	x		x			x			x	12
AchnRecu				*Achnanthes recurvata*														x								1
AchmAffi				*Achnanthidium affine*	*Achnanthes affinis*					x	x	x					x	x	x	x						7
AchmBipo				*Achnanthidium biporomum*	*Achnanthes biporoma*			x		x							x		x						x	5
AchmClev				*Achnanthidium clevei*	*Achnanthes clevei*	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	19
AchmCleA				*Achnanthidium clevei rostratum*	*Achnanthes clevei rostrata*					x														x		2
AchmExig				*Achnanthidium exiguum*	*Achnanthes exigua*					x	x				x	x		x				x	x	x		8
AchmExiA				*Achnanthidium exiguum heterovalvum*	*Achnanthes exigua heterovalva*						x				x											2
AchmHung				*Achnanthidium hungaricum*	*Achnanthes hungarica*								x	x		x										3
AchmLanc				*Achnanthidium lanceolatum*	*Achnanthes lanceolata*	x	x	x	x	x		x			x	x	x	x	x	x	x	x		x	x	16
AchmLanA				*Achnanthidium lanceolatum dubium*	*Achnanthes lanceolata dubia*	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	20
AchmMinu				*Achnanthidium minutissimum*	*Achnanthes minutissima*	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	20
AchmPera				*Achnanthidium peragalli*	*Achnanthes peragalli*		x	x		x					x	x	x	x	x	x	x	x		x	x	13
AchmPusi				*Achnanthidium pusillum*	*Achnanthes pusilla*						x			x	x		x	x	x				x	x	x	9
CoccDimi				*Cocconeis diminuta*							x		x			x	x			x						5
CoccFluv				*Cocconeis fluviatilis*																	x					1

Appendix. Benthic algae found at 20 agricultural benchmark streams in the Western Lake Michigan Drainages study unit, 1993—Continued

[RHU, relatively homogeneous unit; Refer to table 1 for full stream names and locations. This taxonomic hierarchy is based on Bourrelly (1981, 1985, 1988, 1990) for soft algae, Taylor (1987) for dinoflagellates, and Round and others (1990) for diatoms. The taxonomy also included additional recent revisions for diatoms by Bukhtiyarova and Round (1996), Round and Bukhtiyarova (1996), Round and Basson (1997), Krammer (1997a,b), and Lange-Bertalot (1997).]

Code	Division	Class	Order	Taxonomic Name	Comments (alternate nomenclature)	RHU 1					RHU 3				RHU 20					RHU 26						Totals
						TI	KR	LI	CA	HI	EB	NI	MU	WA	WH	WB	SI	SM	CM	LA	NE	CH	ME	WI	PI	
CoccPedi				*Cocconeis pediculus*		x		x	x	x	x		x	x		x					x		x	x		11
CoccPlaA				*Cocconeis placentula euglypta*		x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	19
CoccPlaB				*Cocconeis placentula lineata*							x	x			x		x	x		x	x	x	x	x	x	11
CoccThum				*Cocconeis thumensis*			x	x		x	x	x			x	x	x	x	x	x	x	x	x	x	x	16
			Bacillariales																							
CyniDilu				*Cymbellonitzschia diluviana*										x	x	x	x					x	x	x		7
DentTenu				*Denticula tenuis*						x																1
HantAmph				*Hantzschia amphioxys*			x																			1
NitzAcic				*Nitzschia acicularis*			x						x	x	x					x	x	x	x		x	9
NitzAcul				*Nitzschia acula*													x									1
NitzAdmi				*Nitzschia admissa*																x						1
NitzAmph				*Nitzschia amphibia*		x		x	x		x		x		x			x	x	x		x		x		11
NitzAngu				*Nitzschia angustata*						x																1
NitzBaca				*Nitzschia bacata*										x				x		x						3
NitzBrev				*Nitzschia brevissima*											x				x							2
NitzDise				*Nitzschia diserta*												x	x		x							3
NitzDiss				*Nitzschia dissipata*					x		x				x		x	x	x	x		x	x	x	x	11
NitzDisA				*Nitzschia dissipata media*				x					x	x						x	x	x	x			7
NitzFont				*Nitzschia fonticola*									x	x								x				3
NitzFrus				*Nitzschia frustulum*		x	x	x			x	x								x	x	x		x		9
NitzFruA				*Nitzschia frustulum perminuta*							x	x	x	x	x	x	x	x	x	x						10
NitzFruB				*Nitzschia frustulum subsalina*		x					x							x		x		x	x	x		7
NitzGrac				*Nitzschia gracilis*											x										x	2
NitzKuet				*Nitzschia kuetzingiana*		x	x	x	x	x	x	x	x	x	x			x	x	x	x			x	x	16
NitzLine				*Nitzschia linearis*		x	x	x	x		x		x	x			x		x		x	x	x		x	13
NitzLinA				*Nitzschia linearis tenuis*		x	x		x	x	x	x		x	x		x	x	x	x	x	x			x	15
NitzPale				*Nitzschia palea*								x		x						x	x					4
NitzRect				*Nitzschia recta*		x		x		x	x	x	x	x	x				x							9
NitzRoma				*Nitzschia romana*										x						x		x				3
NitzSimo				*Nitzschia sigmoidea*											x											1
NitzSoci				*Nitzschia sociabilis*				x			x											x	x	x		5
NitzSubt				*Nitzschia subtilis*		x		x		x	x	x	x		x			x		x				x	x	11
NitzTrop				*Nitzschia tropica*										x												1

Appendix. Benthic algae found at 20 agricultural benchmark streams in the Western Lake Michigan Drainages study unit, 1993—Continued

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						TI	KR	LI	CA	HI	EB	NI	MU	WA	WH	WB	SI	SM	CM	LA	NE	CH	ME	WI	PI	
			Cymbellales																							
CymbAffi				*Cymbella affinis*				x		x	x	x			x					x	x	x	x	x	x	11
CymbBreh				*Cymbella brehmii*			x																			1
CymbCesa				*Cymbella cesatii*														x								1
CymbCist				*Cymbella cistula*							x			x						x	x	x			x	6
CymbCusp				*Cymbella cuspidata*														x								1
CymbDeli				*Cymbella delicatula*								x			x											2
CymbDilu				*Cymbella diluviana*							x															1
CymbHauc				*Cymbella hauckii*											x											1
CymbMicr				*Cymbella microcephala*	*Encyonopsis microcephala*					x	x				x		x				x	x				6
EncyMinu				*Cymbella minuta*	*Encyonema minutum*	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	19
CymbMinu				*Cymbella minuta silesiaca*	*Encyonema silesiacum*																	x	x	x		3
EncyMuel				*Cymbella muelleri*	*Encyonema muelleri*									x						x	x					3
CymbNavi				*Cymbella naviculiformis*		x	x														x		x			4
EncyPros				*Cymbella prostratum*	*Encyonema prostratum*		x																	x		2
ReimSinu				*Cymbella sinuata*	*Reimeria sinuata*	x	x	x	x	x	x	x				x	x	x	x		x	x	x	x		15
ReimSinA				*Cymbella sinuata antiqua*	*Reimeria sinuata antiqua*							x														1
GonsErie				*Gomphoneis eriense variabilis*	*Gomphonema eriense variabilis*																	x				1
GompAcum				*Gomphonema acuminatum*		x				x				x												3
GompAffi				*Gomphonema affine*		x	x				x															3
GompAngu				*Gomphonema angustatum*		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x		x	x	18
GompAngA				*Gomphonema angustatum intermedia*																					x	1
GompAngB				*Gomphonema angustatum productum*									x													1
GompAngC				*Gomphonema angustatum sarcophagus*			x		x					x				x								4
GompClev				*Gomphonema* cf. *clevei*				x		x	x	x	x	x							x			x		8
GompGrac				*Gomphonema gracile*																			x			1
GompGrun				*Gomphonema grunowii*							x							x								2
GompMexi				*Gomphonema mexicanum*			x	x																		2
GompOlio				*Gomphonema olivaceoides hutchinsoniana*			x	x		x																3
GompOliv				*Gomphonema olivaceum*	*Gomphoneis olivacea*	x			x		x	x	x	x	x	x					x	x	x	x	x	13
GompParv				*Gomphonema parvulum*		x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	19
GompSubc				*Gomphonema subclavatum*							x															1
GompTrun				*Gomphonema truncatum*		x				x	x			x		x	x			x		x				8

Appendix. Benthic algae found at 20 agricultural benchmark streams in the Western Lake Michigan Drainages study unit, 1993—Continued

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						TI	KR	LI	CA	HI	EB	NI	MU	WA	WH	WB	SI	SM	CM	LA	NE	CH	ME	WI	PI	
GompTruA				*Gomphonema truncatum capitatum*					x				x	x												3
Gsphgrov				*Gomphosphenia grovei*	*Gomphonema grovei*												x									1
RhoiAbbr				*Rhoicosphenia abbreviata*		x	x	x	x		x		x	x		x	x		x	x	x		x	x		14
			Eunotiales																							
EunoCurv				*Eunotia curvata*														x								1
EunoExig				*Eunotia exigua*														x	x							2
EunoMajo				*Eunotia major*												x		x								2
EunoNaeg				*Eunotia naegelii*		x				x		x					x	x	x							6
EunoPecA				*Eunotia pectinalis minor*						x								x								2
EunoTene				*Eunotia tenella*		x																				1
			Naviculales																							
AmphPell				*Amphipleura pellucida*						x																1
CaloAmph				*Caloneis amphisbaena*			x						x	x												3
CaloBaci				*Caloneis bacillum*		x		x	x	x		x	x	x		x	x	x	x	x		x		x	x	15
CaloVent				*Caloneis ventricosa truncatula*		x		x																		2
CratAcco				*Craticula accomoda*	*Navicula accomoda*							x														1
CratCusp				*Craticula cuspidata*	*Navicula cuspidata*												x				x					2
DiadConf				*Diadesmis confervacea*	*Navicula confervacea*						x															1
DiplMarg				*Diploneis marginestriata*			x																			1
DiplOblo				*Diploneis oblongella*														x								1
DiplPuel				*Diploneis puella*				x										x								2
FrusRhoA				*Frustulia rhomboides amphipleuroides*				x							x		x	x	x			x				6
FrusRhoB				*Frustulia rhomboides crassinervia*										x												1
FrusVulg				*Frustulia vulgaris*			x	x	x	x		x			x		x	x	x	x	x	x		x	x	14
FrusWein				*Frustulia weinholdii*												x										1
GyroAcum				*Gyrosigma acuminatum*			x																			1
GyroAtte				*Gyrosigma attenuatum*				x									x					x				3
GyroNodi				*Gyrosigma nodiferum*				x																		1
GyroScal				*Gyrosigma scalproides*								x														1
LutiCohn				*Luticola cohnii*	*Navicula cohnii*						x							x	x			x				4
LutiMuti				*Luticola mutica*	*Navicula mutica*			x																		1
NaviAcce				*Navicula acceptata*				x		x					x	x	x		x			x	x	x		9
NaviArve				*Navicula arvensis*							x															1
NaviBaci				*Navicula bacillum*	*Sellaphora bacillum*											x										1

Appendix. Benthic algae found at 20 agricultural benchmark streams in the Western Lake Michigan Drainages study unit, 1993—Continued

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						TI	KR	LI	CA	HI	EB	NI	MU	WA	WH	WB	SI	SM	CM	LA	NE	CH	ME	WI	PI	
NaviBico				*Navicula biconica*								x													x	2
NaviBryo				*Navicula bryophila*						x					x		x					x		x		5
NaviCapi				*Navicula capitata*		x		x	x		x		x	x		x		x			x					9
NaviCapA				*Navicula capitata hungarica*		x		x			x	x				x	x			x				x	x	9
NaviCapB				*Navicula capitata luneburgensis*																x						1
NaviCari				*Navicula cari*		x		x	x	x	x		x	x	x	x	x	x	x	x	x	x	x		x	17
NaviCinc				*Navicula cincta*				x			x															2
NaviCinA				*Navicula cincta rostrata*		x	x		x		x						x								x	6
NaviClem				*Navicula clementis*			x				x				x				x							4
NaviCont				*Navicula contenta biceps*	*Diadesmis contenta biceps*		x										x									2
NaviConv				*Navicula convergens*											x											1
NaviCryp				*Navicula cryptocephala*		x	x		x		x	x			x	x	x	x	x	x		x	x	x	x	15
NaviCryB				*Navicula cryptocephala veneta*		x				x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	16
NaviDecu				*Navicula decussis*	*Geissleria decussis*	x				x	x	x				x				x	x	x	x	x	x	11
NaviElgi				*Navicula elginensis*	*Placoneis elginensis*													x								1
PlacGast				*Navicula gastrum*	*Placoneis gastrum*	x	x								x				x		x		x			6
NaviGrac				*Navicula graciloides*		x	x	x	x		x	x	x	x		x	x				x					11
NaviGreg				*Navicula gregaria*		x					x										x				x	4
NaviHeuf				*Navicula heufleriana*					x																	1
NaviHust				*Navicula hustedtii*								x														1
NaviIgno				*Navicula ignota*													x									1
NaviIgnA				*Navicula ignota palustris*														x								1
NaviInco				*Navicula incomposita 1 ansnar*																			x			1
NaviInte				*Navicula integra*			x		x		x	x							x							5
SellLaev				*Navicula laevissima*	*Sellaphora laevissima*						x															1
NaviLanc				*Navicula lanceolata*			x		x		x	x	x	x		x	x			x						9
NaviMeni				*Navicula menisculus*		x	x				x	x	x		x	x			x	x		x		x	x	12
NaviMini				*Navicula minima*		x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x		x	18
NaviOchr				*Navicula ochridana*			x					x									x					3
NaviPauc				*Navicula paucivisitata*				x				x							x	x	x	x	x			7
NaviPell				*Navicula pelliculosa*									x	x						x					x	4
NaviPere				*Navicula peregrina*			x			x					x	x			x							5
NaviPerp				*Navicula perpusilla*													x	x								2
NaviProt				*Navicula protracta*							x	x						x								3

Appendix. Benthic algae found at 20 agricultural benchmark streams in the Western Lake Michigan Drainages study unit, 1993—Continued

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						TI	KR	LI	CA	HI	EB	NI	MU	WA	WH	WB	SI	SM	CM	LA	NE	CH	ME	WI	PI	
SellPupu				*Navicula pupula*	*Sellaphora pupula*	x			x	x	x	x	x		x		x	x			x					10
NaviPupA				*Navicula pupula capitata*						x																1
NaviPupB				*Navicula pupula mutata*	*Sellaphora pupula mutata*	x									x					x						3
SellPupA				*Navicula pupula rectangularis*	*Sellaphora pupula rectangularis*							x			x			x		x				x		5
NaviRadi				*Navicula radiosa*		x			x	x	x	x						x		x	x					8
NaviRadB				*Navicula radiosa tenella*				x																		1
NaviRhyn				*Navicula rhynchocephala*														x	x							2
NaviRhyA				*Navicula rhynchocephala germainii*							x	x													x	3
NaviSalA				*Navicula salinarum intermedia*		x			x	x	x	x	x	x		x		x		x	x	x	x			13
NaviScut				*Navicula scutelloides*							x					x							x	x		4
NaviScum				*Navicula scutiformis*												x										1
NaviSecr				*Navicula secreta apiculata*		x	x	x	x		x	x	x	x	x	x	x		x				x	x	x	15
NaviSemi				*Navicula seminuloides*				x			x		x			x		x	x			x	x			8
NaviSp.1				*Navicula sp. 1 ans hdsn*								x														1
NaviSymm				*Navicula symmetrica*							x															1
NaviTant				*Navicula tantula*			x								x	x	x	x	x	x				x		8
NaviTrip				*Navicula tripunctata*		x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	19
NaviTriA				*Navicula tripunctata schizonemoides*					x	x		x		x	x			x			x	x	x	x		10
NaviTusc				*Navicula tuscula*						x																1
NaviVirB				*Navicula viridula avenacea*					x		x	x	x	x		x	x				x	x				9
NaviVirC				*Navicula viridula linearis*							x															1
NeidAffi				*Neidium affine*					x																	1
NeidBisu				*Neidium bisulcatum*					x									x								2
NeidDubi				*Neidium dubium*							x															1
NeidHank				*Neidium hankensis*																x	x					2
PinnAbaA				*Pinnularia abaujensis linearis*														x								1
PinnAcro				*Pinnularia acrosphaeria*														x								1
PinnInte				*Pinnularia intermedia*														x								1
PinnMajo				*Pinnularia major*								x						x	x							3
PinnMes1				*Pinnularia mesogongyla*														x								1
PinnNodo				*Pinnularia nodosa*														x								1
PinnObsc				*Pinnularia obscura*														x								1
PinnViri				*Pinnularia viridis*						x																1
SellSemi				*Sellaphora seminulum*	*Navicula seminulum*		x									x	x	x		x		x	x		x	8

Appendix. Benthic algae found at 20 agricultural benchmark streams in the Western Lake Michigan Drainages study unit, 1993—Continued

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Code	Division	Class	Order	Taxonomic Name	Comments (alternate nomenclature)	RHU 1					RHU 3				RHU 20					RHU 26						Totals
						TI	KR	LI	CA	HI	EB	NI	MU	WA	WH	WB	SI	SM	CM	LA	NE	CH	ME	WI	PI	
StneAncA				*Stauroneis anceps gracilis*					x																	1
StneKrie				*Stauroneis kriegeri*			x								x		x	x	x							5
StnePhoe				*Stauroneis phoenicenteron*			x																			1
StneSmit				*Stauroneis smithii*				x	x	x		x						x		x	x					7
StneTher				*Stauroneis thermicola lanceolata*														x								1
			Rhopalodiales																							
EpitArgu				*Epithemia argus*							x															1
EpitTurg				*Epithemia turgida*							x															1
			Surirellales																							
CymaEllA				*Cymatopleura elliptica hibernica*						x																1
CymaSole				*Cymatopleura solea*					x	x	x				x	x			x		x					7
SuriAngu				*Surirella angusta*		x	x				x		x						x							5
SuriBrig				*Surirella brightwellii*										x												1
SuriMinu				*Surirella minuta*							x	x	x	x							x				x	6
			Thalassiophysales																							
AmpoAngu				*Amphora angusta*																x						1
AmpoOval				*Amphora ovalis*		x		x	x	x			x		x	x	x				x	x		x	x	12
AmpoOvaB				*Amphora ovalis pediculus*		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	20
AmpoPerp				*Amphora perpusilla*		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	20
AmpoSubm				*Amphora submontana*			x				x															2
		Coscinodiscophyceae																								
			Aulacoseirales																							
AulaAmbi				*Aulacoseira ambigua*	*Melosira ambigua*						x															1
AulaGran				*Aulacoseira granulata*	*Melosira granulata*						x															1
AulaItal				*Aulacoseira italica*	*Melosira italica*													x	x							2
AulaItaA				*Aulacoseira italica tenuissima*	*Melosira italica tenuissima*													x	x							2
			Melosirales																							
MeloVari				*Melosira varians*		x	x		x		x	x	x	x		x	x	x		x		x	x			13
			Thalassiosirales																							
CyclDist				*Cyclotella distinguenda*						x														x		2
CyclKuet				*Cyclotella kuetzingiana*			x			x			x	x							x					5
CyclMene				*Cyclotella meneghiniana*		x	x		x		x	x	x	x	x	x	x		x						x	12
CyclStri				*Cyclotella striata*																				x		1
StepMinu				*Stephanodiscus minutulus*									x	x												2

Appendix. Benthic algae found at 20 agricultural benchmark streams in the Western Lake Michigan Drainages study unit, 1993—Continued

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StepParv				*Stephanodiscus parvus*																			x			1
		Fragilariophyceae																								
			Fragilariales																							
AsteForm				*Asterionella formosa*							x															1
DiatTenA				*Diatoma tenue elongatum*						x	x	x									x	x		x		6
DiatVulg				*Diatoma vulgare*					x	x		x	x	x						x	x	x		x	x	10
PseuBrev				*Fragilaria brevistriata*	*Pseudostaurosira brevistriata*		x	x		x	x				x	x	x	x		x	x	x	x		x	13
FragBrev				*Fragilaria brevistriata inflata*							x											x				2
FragCapu				*Fragilaria capucina*														x								1
FragCapA				*Fragilaria capucina mesolepta*					x		x						x			x	x	x	x			7
StsiCons				*Fragilaria construens*	*Staurosira construens*	x			x	x	x		x	x	x	x	x	x	x		x	x	x	x		15
FragConA				*Fragilaria construens binodis*	*Staurosira construens binodis*				x							x		x								3
FragConB				*Fragilaria construens pumila*			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	19
FragConD				*Fragilaria construens venter*	*Staurosira construens venter*	x	x	x	x	x	x	x			x	x	x	x	x		x	x	x	x		16
StreLept				*Fragilaria leptostauron*	*Staurosirella leptostauron*	x	x			x		x			x	x	x	x	x	x	x	x	x			13
StrePinn				*Fragilaria pinnata*	*Staurosirella pinnata*	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	20
FragPinB				*Fragilaria pinnata lancettula*		x	x		x	x					x	x	x	x	x	x	x	x	x	x		14
PseuRobu				*Fragilaria robusta*	*Pseudostaurosira robusta*												x			x	x					3
FragVauc				*Fragilaria vaucheriae*		x	x		x		x	x	x	x	x	x	x			x	x	x		x	x	15
FragVirB				*Fragilaria virescens exigua*			x															x				2
MartMart				*Martyana martyi*	*Fragilaria leptostauron martyi*	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	19
MeriCirc				*Meridion circulare*		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	19
MeriCirA				*Meridion circulare constrictum*							x							x	x							3
SyneAcus				*Synedra acus*		x							x		x					x		x				5
SyneDeli				*Synedra delicatissima angustissima*										x					x						x	3
SynePara				*Synedra parasitica*					x	x	x		x	x			x					x				7
SyneParA				*Synedra parasitica subconstricta*							x	x														2
SyneRump				*Synedra rumpens*		x			x	x	x	x	x	x	x		x	x		x		x				12
SyneRumA				*Synedra rumpens familiaris*				x												x	x	x		x		5
SyneRumC				*Synedra rumpens meneghiniana*		x	x	x	x		x		x	x	x	x				x	x	x	x		x	14
SyneTene				*Synedra tenera*									x	x			x	x			x			x	x	7
SyneUlna				*Synedra ulna*		x	x	x	x	x	x		x	x	x	x	x	x	x		x	x		x	x	17
SyneUlnA				*Synedra ulna oxyrhynchus*		x				x	x		x	x			x			x	x	x	x	x		11

Appendix. Benthic algae found at 20 agricultural benchmark streams in the Western Lake Michigan Drainages study unit, 1993—Continued

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						TI	KR	LI	CA	HI	EB	NI	MU	WA	WH	WB	SI	SM	CM	LA	NE	CH	ME	WI	PI	
			Tabellariales																							
TabeFene				*Tabellaria fenestrata*						x	x															2
TabeFloc				*Tabellaria flocculosa*														x								1
	Chlorophyta																									
Chlorop2				*Chlorophyta* (undet) (coccoid)																	x					1
		Chlorophyceae																								
			Chaetophorales																							
SchiLeib				*Schizomeris leibleinii*						x										x						2
StigLubr				*Stigeoclonium lubricum*																x				x		2
			Chlorococcales																							
AnkiFalc				*Ankistrodesmus falcatus*											x											1
CeraStau				*Cerasterias staurastroides*																	x					1
ScenQuad				*Scenedesmus quadricauda*							x	x										x				3
ScenSpin				*Scenedesmus spinosus*						x	x										x					3
			Chlorosarcinales																							
DrapGlom				*Draparnaldia glomerata*																				x		1
			Oedogoniales																							
OedogSp.				*Oedogonium* sp.													x		x							2
			Tetrasporales																							
TetrLubr				*Tetraspora lubrica*																				x		1
			Zygnematales																							
ClosAcer				*Closterium acerosum*									x	x						x						3
ClosKutz				*Closterium kutzingii*														x								1
ClosMoni				*Closterium moniliferum*											x					x	x	x				4
CosmMoni				*Cosmarium moniliforme*											x											1
CosmUndu				*Cosmarium undulatum*															x							1
MougSp.				*Mougeotia* sp.							x							x								2
SpiroSp.				*Spirogyra* sp.			x				x				x						x					4
ZygnSp.				*Zygnema* sp.																	x					1
		Ulvophyceae																								
			Cladophorales																							
CladGlom				*Cladophora glomerata*		x	x	x	x	x			x	x							x		x	x	x	11

Appendix. Benthic algae found at 20 agricultural benchmark streams in the Western Lake Michigan Drainages study unit, 1993—Continued

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						TI	KR	LI	CA	HI	EB	NI	MU	WA	WH	WB	SI	SM	CM	LA	NE	CH	ME	WI	PI	
	Chrysophyta																									
		Chrysophyceae																								
			Ochromonadales																							
DinoCyli				*Dinobryon cylindricum*											x											1
	Cyanophyta																									
Cyanoph1				*Cyanophyta* (undet coccoid 3-5um)				x						x											x	3
Cyanoph2				*Cyanophyta* (undet coccoid)															x							1
Cyanoph3				*Cyanoophyta* (undet) sp.				x	x	x							x	x	x							6
		Cyanophyceae																								
			Chamaesiphonales																							
ChamRegu				*Chamaesiphon regularis*		x								x	x					x				x		5
			Chroococcales																							
GospLacu				*Gomphosphaeria lacustris*							x															1
MemoSp.				*Merismopedia* sp.																	x					1
MemoTenu				*Merismopedia tenuissima*											x											1
			Nostocales																							
AnabaSp.				*Anabaena* sp.																x	x					2
CalxPari				*Calothrix parietina*		x	x		x	x	x	x	x	x			x			x	x	x		x	x	14
HydrBreb				*Hydrocoleum brebissonii*									x		x					x		x	x	x	x	7
LyngMart				*Lyngbya martensiana*		x		x	x		x	x	x	x		x		x	x	x	x			x	x	14
LyngSp.1				*Lyngbya* sp. 1 (ansfwa)		x	x				x	x						x	x	x	x		x	x		10
MiccVagi				*Microcoleus vaginatus*			x								x					x						3
OsciSp.1				*Oscillatoria* sp. *1* (ansfwa)											x	x	x	x	x	x			x			7
OsciSp.4				*Oscillatoria* sp. *4* (ansfwa)			x		x						x					x						4
	Euglenophyta																									
		Euglenophyceae																								
			Euglenales																							
EuglAcus				*Euglena acus*					x															x		2
EuglSp.1				*Euglena* sp.					x									x		x	x					4
LepoFusi				*Lepocinclis fusiformis*																	x	x				2
LepoSp.				*Lepocinclis* sp.											x											1
PhacSp.				*Phacus* sp.						x																1
TracSp.				*Trachelomonas* sp.						x																1
TracSp.1				*Trachelomonas* sp. *1* (ansfwa)			x	x							x		x					x				5
TracSp.2				*Trachelomonas* sp. *2* (ansfwa)											x					x	x	x				4

Appendix. Benthic algae found at 20 agricultural benchmark streams in the Western Lake Michigan Drainages study unit, 1993—Continued

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						TI	KR	LI	CA	HI	EB	NI	MU	WA	WH	WB	SI	SM	CM	LA	NE	CH	ME	WI	PI	
	Rhodophyta																									
		Florideophyceae																								
			Nemaliales																							
AudoHerm				*Audouinella hermanii*	*Audouinella violacea*	x	x		x	x	x	x	x	x	x							x	x			11
	Xanthophyta																									
		Xanthophyceae																								
			Mischococcales																							
OphiCapi				*Ophiocytium capitatum*														x								1
			Vaucheriales																							
VaucSp.				*Vaucheria* sp.				x				x				x						x				4